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NEW DEVELOPMENTS IN BIOTECHNOLOGY: U.S. INVESTMENT IN BIOTECHNOLOGY

Contractor Reports: Part 3

Public and Private Sector Roles in the Funding of Agricultural Biotechnology Research

December 1987

Pubic and Private Sector Roles in the Funding of Agricultural Biotechnology Research, Jack Doyle, Environmental Policy Institute, Washington, D.C.

Public and Private Sector Roles in the Funding of Agricultural Biotechnology Research, Richard A. Herrett and Richard J. Patterson

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PUBLIC AND PRIVATE SECTOR ROLES IN THE FUNDING OF AGRICULTURAL BIOTECHNOLOGY RESEARCH

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Submitted to U.S. Congress Office of Technology Assessment, Biological Applications, by Jack Doyle, Director, Agricultural Resources Project, Environmental Policy Institute, Washington, D.C., 30 June 1987.

Since the early 1980s, agricultural biotechnology has been touted as the next "green revolution", and more recently as the nation's single best tool to make American farmers competitive in world markets. Others have suggested that biotechnology will make crops "immune" to disease and insects, or be capable of fixing their own nitrogen. Still others have said that biotechnology will make possible a new generation of "environmentally friendly" products, potentially displacing toxic pesticides. (Schneiderman, 1986).

But despite all the promises being made for agricultural biotechnology, there are questions about what is being researched, how soon safer products will come, what will be capitalized first, who will bring the inventions to market, and at what cost? With these concerns, there is a renewed focus on the nation's agricultural research system--a system that is lodged partly in the private sector and partly in the public sector. At issue is how agricultural biotechnology research will be prioritized, what lines of research ought to be pursued, and what research roles are appropriate for the respective public and private sector research institutions. One major concern at the center of this debate is the funding source --be that the federal government, a publicly-supported university, or a private-sector corporation. A key question here is whether, and to what extent,

the source of funding is influencing the research agenda, and in some measure, the shape of the farm and food system that follows from that research ?

Who Is Determining the Research Agenda? And What is Being Pursued?

In November 1984, David Call, Dean of Cornell University's College of Agriculture and Life Sciences told the Wall Street Journal: "We'd been plodding along unnoticed for 100 years convinced we were doing something nobel--feeding the world. Now, all of a sudden, outsiders want us to justify how we pick our research projects and how we spend our research dollars. The scientists are shocked." (Bellew, 1984)

In the years ahead, public scrutiny of agricultural research from a number of perspectives is likely to intensify. In recent years, in fact, the system has had a good deal of criticism; criticism that will shape the debate over biotechnology and research priorities as well. These critic groups can be loosely organized as follows:

First, there are the basic science advocates, those who charge that the USDA-led system has not been on the "cutting edge" of science, and has not been paying enough attention to basic research. Essentially, there have been two periods of concern over basic science R&D: one triggered by the world food

crisis of 1972-73, and the second-- extending and refueling the earlier concerns--brought on by the opportunities for agricultural advancement with the new biotechnologies.

Second, the USDA system is increasingly challenged by consumers, environmentalists, farmworkers, and rural development advocates who have a range of concerns and research priorities. Some of this criticism has been going on since 1962, with the publication of Rachel Carson's Silent Spring. But in the last 10 years or so, much of it has focused on corporate intrusion into, and domination of, public sector research, raising questions about the land grant complex in particular, and whose interests this system is serving. This latter focus on "land grant accountability", as it is sometimes called, began in large measure with the 1973 publication of Hard Tomatoes, Hard Times, written by Jim Hightower, who is now Commissioner of Agriculture for the state of Texas.[1]

Today, the concern for land grant accountability is presently before the courts in Califorinia, where a 1979 lawsuit challenging a federally-supported University of California research project on the labor-displacing aspects of a tomato

1 Hightower, found, for example, that: Iowa State University scientists helped to develop the hormone DES (diethylstilbestrol), which was used widely in cattle feed and later found in clinical testing to carcinogenic; that Texas A & M researchers assisted Union Carbide with its experimental work in developing Temik, a highly poisonous insecticide which in the 1980s was found resposible for groundwater and drinking water contaminantion in potato-grwoing regions of New York and Wisconsin; and that the Kansas State University Extension Service conducted research to determine how mirrors and reflected light might be used in supermarkets to make fruit and vegetalbe look better.

harvester, is about to come to a conclusion. At issue is not only the impact of federally-funded research on small farmers and farmworkers, but also broader questions pertaining to other social impacts of publicly-sponsored research on the rural community, consumers, and the environment. The Hatch Act of 1887 is part of the basis for this suit, which was originally brought by California Rural Legal Assistance on behalf of 19 farmworkers and the Califorinia Agrarian Action Project, a public interest organization. (see for example, Bishop, 1987; Lindsey 1984; Hager, 1984).

A third category of critics recently emerging with the onset of biotechnology have been farmers and other user groups questioning certain research thrusts that may be having untoward economic consequences on their operations and communities. One example of the concerns from this group is the research and development of a genetically engineered bovine growth hormone for use on dairy cows (discussed below in Case Study #1).

Much of the criticism coming from these disparate interests is now heigthened by, and collapsed into, the debate surrounding the allocation, distribution and reorientation of public and private resources for research on agriculutral biotechnology; what research should be done, and by whom, and for whose benefit. Moreover, the critics involved in this debate are more than merely armchair participants; they represent very active political constituencies that can affect funding levels, federal

and state legislation, and public opinion.

The New Setting

In the last decade or so, a series of key scientific, economic, and legal developments have come together in a unique way to affect how commercial and governmental interests are now approaching the biological sciences and agricultural research.

First, there is biotechnology and genetic engineering. At the center of this technology is DNA--deoxyribonucleic acid--the new raw material that is rapidly making obsolete the old lines of distinction that once separated chemistry, pharmacology, energy, food, and agriculture. DNA is now a common language to all of these sciences—collectively called the "life sciences".

Second, there is patenting, the legal basis to have a property right and to maintain a limited monopoly in the market for 17 years. Patenting "rights" in the biological and genetic realms have been dramatically expanded in the U.S. since 1970. As it stands today, in the context of biotechnology, patents are now available for seeds, plants, microbes, animals, and it appears, individual genes as well.

Third, there is rampant economic consoldiation throughout the life sciences industries, including agribusiness. Since 1981, there have been mergers of huge proportion, as in the

pairings of Du Pont/ Connoco, Nestle/Carnation, Gulf/Chevron, Hoechst/Celanese, and Monsanto/G.D.Searle, to name a few. Mergers and acquisitions of this kind are continuing today at an unprecedented rate and scale, creating multinational corporations that have a full complement of in-house research capabiliteis in molecular biology, as well as well as extensive extramural funding of, and collaboration with, universities and other publicly-funded researchers. Questions here concern the potential lack of competition and the relationship of that situation on what is researched.

Fourth, to some extent, the boom in start-up biotechnology companies in plant and animal agriculture, as well as major corporate product research in these areas, has come at the expense of the public sector, with talented scientists,[2] and in some instances, research materials, leaving the public sector and moving to the private sector. A biological sciences "brain drain" has occurred with the corpoate search for scarce scientists. Moreover, teaching and research faculty with one foot in the univeristy and another in a biotech company is also common today in many schoools, raising questions about the quality of education and research loyalties of faculty whose time is divided between two different places.

---

2 In a 1985 survey of companies engaged in agricutlural biotechnology, conducted by the National Association of State Universities and Land Grant Colleges, it is noted that between 15-to-24% of the agricultural scientists in the responding companies were previously employed as university scientists (NASULG, 1986).

Fifth, there is the new development of government-encouraged research collaboration between industry, university, and government agencies--much of it being formed under the rubric of maintaining and increasing U.S. competitiveness. This trend is worrisome at both the state and federal levels because it blurs the role of government as regulator and the university as society's neutral arbiter and advisor. Meanwhile, within the Congress, there have been measures approved that have allowed for more industry/university collaboration, more industry/industry research collaboration, and tax incentives for private investment in research.

Sixth, at the state level in recent years, a number of legislatures and state government agencies, often working with universities, have initiatied special appropriations or created new research programs in biotechnology, some forming new "biotechnology centers" or "centers-of-excellence" programs. Some programs are university-initiated through the legislatures. At least 31 states have now created some form of biotechnology program, with a number of these including or emphasizing agricultural biotechnology (see Table)[3] .

Seventh, at the federal level there has been a movement in the direction of more funding for agricultural biotechnology

3 The agricultural biotechnology programs of Ohio, North Carolina, Washington, and Wisconsin are discussed in Appendix ___ and are offered as representative, though not exhaustive, examples of what some states are doing in agricultural biotechnology.

TABLE 1.

SPECIAL STATE/UNIVERSITY INITIATIVES CREATING
BIOTECHNOLOGY RESEARCH CENTERS
WITH SOME INVOLVEMENT IN AGRICULTURAL RESEARCH

State	Year	Nature of Center/Institute
Indiana		Purdue University Agrigenetics Center
Iowa		state legislature has allocated $18 million to Iowa State Univ. for agricultural biotechnology research over the next 4 yrs.
Georgia		state legislature has appropriated $7.5 million for the construction of a $32 million Center for Biotechnology at the Univ. of Georgia. Biotech research there will focus on cattle, hogs & peaches
Maryland		Center for Advanced Research in Biotechnology at Univ. of Maryland; agriculture is one of 5 research areas
Michigan	1981	state-created Michigan Biotechnology Institute at Michigan State Univ.will focus on plant genetic engineering & tissue culture work related to state's forest industry
Missouri		Food for The 21st Century center at Univ. of Missouri--Columbia
New York	1983	Biotechnology Institute created at Cornell; university is also designated a "center for advanced technology" by the New York State Science & Technology Foundation; Kodak, General Foods & Union Carbide have each pledged $2.5 million for the Institute over a six year period. Both centers will "foster basic biotechnology research and application to benefit agriculture, food, chemical and pharmaceutical industries" in N.Y.
North Carolina	1981	state-created North Carolina Biotechnology Center includes agriculture & forestry as one of its R & D programs; also has fellowship program in plant molecular biology
Ohio		The State-sponsored Thomas Edison Program has established an animal biotechnology center at Ohio University in Athens

Ohio	1985	"Ohio 21" program at Ohio State University establishes a state-funded Ohio Agriculutral Research & Development Center with plant biotech team in Columbus & animal biotech team in Wooster; also additional funds for Ohio Cooperative Extension Service; initiated with $9.1 million (85-87) & expected $12.7 million (87-89); also includes forestry & food biotech
Oklahoma		Oklahoma State Univ. at Stillwater is building a $30 million "21st Century Center" to focus on agricultural biotechnology, water resoruces, and renewable energy
Pennsylvania	1982	A Cooperative Program in Recombinant DNA Technology was established at the Pennsylvania State University as a vehicle for excahnge of information between a group of research faculty and six biotechnology-related industries. In exchange for information, member industries provide $15,000 /yr in the form of a tax-deductible grant-in-aid to the university.
Pennsylvania	1984	A Penn State Biotechnology Institute established with some state funding; objective is to provide educational program & modern service facilities to benefit university, government and industrial affiliates; research program to focus on biotechnology in pharmaceutical, agricultural and chemical industries
Wisconsin		Biotechnology Center--University of Wisconsin

Source: Various state documents, biotechnology program brochures, and newpaper and periodical accounts.

research. However, since about 1978, there has been less interest on the part of the federal government, and particularly the White House science office, the National Academy of Sciences, and NSF, in funding this research within the traditional land grant system. There has been considerably more interest in giving universities outside the land grant system (with the exception of a few major land grants like Cornell, the UC system, Wisconsin, etc.) more opportunity to receive federally appropriated agricultural research money.

Eighth, within the land grant community, there is a growing division between the bigger and better funded schools and those that are not so well positioned to exploit the new funding opportunities for biotechnology. Some have referred to this as the creation of "have" and "have not" universities.[4] The practice of lobbying for capital and building funds in Congress by individual universities (predominantly by the better off ones) will widen the gulf between have and have not universities in the years ahead.

And finally, although there are a few signs to the contrary, the agricultural biotechnology research agenda in both the public and private sectors, appears to be moving in the

4 For example, OTA noted in 1986: "...Reality suggests that only certain universities have sufficient resources to compete for private sector support in biotechnology and information technology. The result is a confluence of forces that is creating a dichotomy of "have and have not" universities. In the process, traditional extension-research interaction and feedback could break down, particularly in states that are not in a position to command a major biotechnology component. (OTA, Changing Structure, 1986).

direction of: furthering the traditional high-yield orientation, continuing and extending (in new ways) the use of synthetic fertilizers and chemical pesticides, and embarking on a microbial genetic engineering course for pest management. This agenda appears, increasingly, to be dominated by a "what-can-be-made-into-a-product" mentality, (which is driven to some extent by new patent allowances), rather than a research agenda that focuses on the application of new molecular- and cellular-based knowledge in agriculture. This latter agenda would pursue more non-engineered biological pest control options, host-based genetics, and cultural management practices in the field, rather than simply extend the "treatment" approach in agriculture with additional products made by biotechnology.

These trends, collectively, are contributing to an overall weakening of the public sector role in agricutlural research, and a corrorllary strengthening of the research position and interests of private-sector biotechnology companies and major corporations. This erosion of the public interest in agricultural research may not bode well for the best interests of the nation, particularly if a high-cost/high-yield/high-risk system of agricultural research is pursued, rather than low-input/low-cost agricultural research options.

Background

Prior to the 1860's, agriculture in the United States was hardly considered worthy of science. While there were always a number of individuals who experimented with agricultural practices and plant and animal breeding--among them, George Washington at Mount Vernon, who first offered a formal proposal for a federal agency devoted to agriculture-- no serious institutional effort at research was formalized until 1862. That was the year in which the U.S. Department of Agriculture was created, the Homstead Act passed, and the Morrill Act became law.

The Morrill Act, passed in July of 1862, provided grants of land (30,000 acres for each Senator and representative in Congress) for the endowment, support and maintenance of colleges of agriculture and the mechanic arts. The land-grant colleges were orginally envisioned as "people's universities"--places of higher education for the common man, where "tillers of the soil" would have their own colleges of agriculture. Following the Morrill Act, another land grant act in 1890, often called the second Morrill Act, was passed by Congress that established "separate but equal" land grant colleges for blacks in 17 southern and border states. But the Morrill Acts of 1862 and 1890 constituted only the first of a three-part system consisting of colleges, experiment stations, and extension services--all of which would become known as the land-grant complex.

Congress followed the first Morrill Act with the Hatch Act of 1877, authorizing direct federal payments to any state that would establish an agricultural experiment station in connection with its land grant college. And in 1914, the final component of the land grant system--the agricultural extension service--was created by the Smith-lever Act to bring the discoveries and science of the land grant univerisites and experiment stations directly to the people through the services of "extension agents".

Today, the three-part complex of the land grant system forms a huge and sprawling publicly-funded research and educational complex consisting of thousands of scientists, students and technical personnel. This federal/state agricultural complex includes the nation's 72 land grant universities, 146 agricultural experiment stations, and thousands of extension agents--one in virtually every county of the United States. The land grant universities alone enroll more than 1.5 million graduate and undergraduate students, and include schools ranging from Purdue, Auburn and MIT, to Montana State University, Lincoln University and Delaware State College. With its legions of plant pathologists, agricultural economists, animal scientsts, molecular biologists and other assorted specialists, the land grant complex, through its application of science, has been reponsible for revolutionizing and some say, industrializing agriculture.

The Changing Funding Mix

For most of its existance, the nation's agricultural research system has been modestly funded by the federal government. In fact, by modern standards, today's federal funding for agricultural research is small indeed, especially when compared to the research budgets of other agencies. Among the major Federal research agencies that conduct research and development, USDA expenditures are the lowest in terms of actual dollar expenditures. And in terms of USDA's total budget, research expenditures constitute a small amount. In recent years, the agricultural research share of all federal R & D is about 1.5 percent, and only 2 percent of USDA's overall budget.

In its May 1987 study of agricultural biotechnology and competitiveness, the National Academy of Sciences says that the current total annual expenditure for agricultural research by federal, state, and private institutions is "roughly $4 billion". Of that amount, private industry spends $2.1 billion annually, mostly on proprietary technology development. The remaining $1.9 billion is contributed by the federal-state agricultural research system. (NAS, May 1987). Others have argued that private sector contribution may be as high as $3 billion, and that a significant shift has occurred at any rate:

> The current magnitude of private sector commitment to agricultural research is largely unknown, although studies suggest that it may approach $3 billion, particularly with the recent

Figure 1.

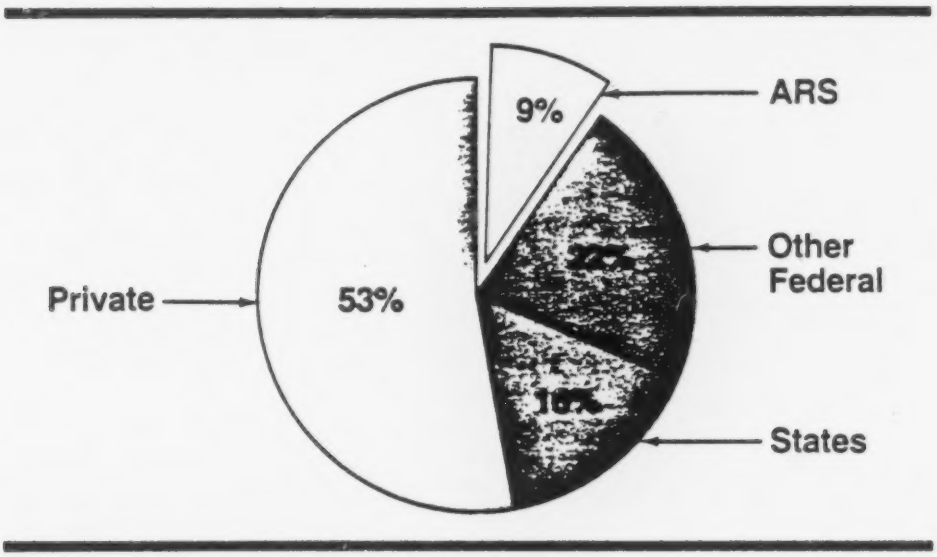

FIGURE 3.—Public and private funds for U.S. food and agricultural research.

Source: USDA, Agricultural Research Service, Agricultural Research Service Program Plan, January 1983, p.8

> increases in private funding. That makes the private sector research commitment approximately equal to or potentially larger than the public sector commitment and represents a major shift toward private sector dominance of agricultural research. (OTA, 1986)

Actually, there have been multiple shifts in agricultural research funding, which taken together are affecting changes in the overall public sector research orientation. These shifts are being expressed in several ways: 1) shifts within the public sector itself, away from formula-based, Hatch Act funding to more competitive grants funding; 2) shifts in the state-federal funding ratios, with substantially greater shares in public funding occurring at the state levels in some states; and 3) a shift toward more private sector participation in, and/or sponsorship of, public sector research by commodity groups, biotechnology companies, and major corporations.

Today, for example, Purdue University's agricultural experiment station recieves about 45 percent of its funding through state and federal appropriations; 25-30 percent from state and federal research grants; 10 -15 percent from industrial/foundation grants and gifts; and the remainder from income-generating sources and miscellaneous categories. In other words, about 85-90 percent of the support and income is from the public sector, while 10 to 15 percent is from the private sector. Yet, in the non-appropriated sponsored research category, industrial/foundation sources can often be the biggest single

source of funds. This issue is discussed in more detail in a later section.

Agricutural Research & The Public Purpose

Today, as biotechnology comes on the scene, it is important that the American people remember that they have invested heavily in the nation's agricultural research system, as well as the science that now makes biotechnology possible. "The scientific advances that made biotechnology possible", says the National Academy of Sciences in its recent study, Agricultural Biotechnology: Strategies for National Competitiveness, "came out of basic research funded mainly by the federal government and carried out primarily at universities". (NAS, 1987, p.7.) Therefore, given this investment, the public has a right to say what should be pursued in research and how biotechnology should be used in agriculture.

Implied in the public funding of agricultural research--including basic research in the biological sciences that contributes to agricultural returns of one kind or another--is responsibiity to the public. For its investment in agricultural research, the public is entitled to broad benefits. These benefits come quite obviously in the form of an assured and safe

food supply and reasonable prices for food, but they may also include stable rural economies, protection of agricultural resources, and minimization of public health costs and environmental side effects that may result from farm production.

Recently, some participants in the agricultural research system have suggested an even broader responsibility for agricultural research in the context of biotechnology. USDA's Users Advisory Board, in its 1988 budget report to the President and Congress, noted the following:

> The needs that the Nation chooses to meet will determine the sucess of biotechnology. And in a heavily subsidized industry, it is the Nation as a whole that indirectly selects the objectives of research. Need is still the mother of invention, but it will be the Nation's needs as represented by diverse groups rather than only the needs of the market. There are social needs--plentiful and low-cost foods; economic needs--low costs (for farmers), high productivity; rural development needs--high employment in rural areas; national needs--reduced entitlement payments.
>
> The Nation may well view technology as a way to improve the profitability of all farm operators, to protect the environment, to preserve the rural community, and to strengthen U.S. agriculture in world markets... (UAB, 1987)

It has long been argued that the land grant universities were established to serve a broad social purpose that goes well beyond farmers and improving farm productivity, but extends also to the welfare of the rural community. Public sector research, in this sense, is something available to all, for the general good.

"The land-grant university system was established on a public service basis different from that of other universities", explains OTA in its 1986 study, Technology, Public Policy, and the Changing Structure of American Agriculture,. "Its tradition has implied a social contract that makes its discoveries freely available to the public".

It is clear from the legislation creating the land grant complex that the institutions invloved were to have more than just a narrow "workbench" or "efficiency" mission in their various research and extension tasks, and that their constituency was more than just agricultural production or farm-related business. One of the responsibilities articulated was to "owner-operated family farms".[5] Indeed, this intent of the land grant complex was reaffirmed by Congress in the National Agricultural Research, Extension and Teaching Act of 1977 and the 1977 farm bill, which noted, in part, that "the family farm system of agriculture is essential to the social well-being of the Nation", and that, "it is the policy and the express intent

---

5 For example, the Bankhead-Jones Act of 1935, provided additional funds for basic research into the laws and principles relating to agriculture, the further development of cooperative extension work, and the more complete endowment and support of the land grant colleges. In writing up the act in 1950, USDA isssued a monograph which stated, in part:

> The Bankhead-Jones Farm Tenant Act may be said to have had its origin in a national tradition. That tradition is a belief in the economic and social values of owner operated family farms. To such farms in no small measure the great middle class in American society owes its origin. Upon such farms in no small measure the middle class must depend for continued influence in shaping the destineies of our democracy... (Hightower, 1973)

of Congress that no (agricultural or agriculture-related) programs be administered in a manner that will place the family farm operation at an unfair economic disadvantage" (P.L. 95-113, section 102). Similar language appears in the 1981 farm bill. (P.L. 97-98, section 1608).

Moreover, in the language of the Hatch Act of 1887[6] and subsequent amendments, there is reference to the "improvement of rural home and rural life", "the welfare of the consumer", and the promotion of "a sound and prosperous agriculture and rural life as indispensable to the maintenanace of maximum employment and national prosperity and security..." (7 U.S.C. 361c)

Other observers and students of agricultural research, such as Vernon Ruttan, have noted some of the principal reasons and the public rationale for the nation's investment in agriculutral research:

> The primary reason for public investment in agricultural research has been that, in many areas, incentives for private research are inadequate.

6 Section 2 of the Hatch Act of 1887 states the purpose of the federal-grant research program as follows: "It is the policy of Congress to promote the efficient production, marketing, distribution and utilization of farm products as essential to the health and welfare of our people...It shall be the object and duty of the State agricultural experiment stations through the expenditure of the appropriations...to conduct original and other researches, investigations, and experiments bearing directly on and contributing to the establishment and maintenance of a permanent and effective agricultural industry of the United States, including researches basic to the problems of agriculture in its broadest aspects, and such investigations as have for their purpose the development and improvement of the rural home and rural life and the maximimum contribution by agriculture to the welfare of the consumer..."

> That is, the social return exceeeds private profit because a large share of the gains from private reseaerch are captured by other firms, by producers, and by consumers.
>
> A second reason for public investment is its complementarity with education. There is a synergistic interaction between research and education in the agricultural sciences...
>
> A third argument for public research is that it contributes to the maintenance or enhancement of a competitive structure in the agricultural production, farm supply, and marketing sectors. For example, the flow of new technology from public research and development has contributed to competition in the seed and fertilizer industries. (Ruttan, 1982).

In 1980, former Secretary of Agriculture Bob Bergland was caught in the middle of the "mechanization case" controversey, involving the issue of whether federal funds should be used on research projects that put farmworkers out of work. In Fresno, at a press conference in December 1979, he stated he would not put USDA mcney into such projects. In defending his position in a later speech, Bergland made some rather eloquent points about the role of federally sponsored research:

> ...I find it difficult if not impossible to justify the use of federal funds to finance research leading to the development of machines or other technologies that may increase production and processing efficiency, but at the same time damage the soil, pollute the environment, displace willing workers, and reduce or eliminante competition.
>
> I do not believe a federally financed research effort ought to benefit a small number of individuals, corporations, or narrow interest groups to such an extent and in such a way as to makit it possible, in time, for the beneficiaries to gain control of the farm-to-market structure, monopolize the sources of finance at every step, and increase their profits by selling what may well be an inferior product at a price that

is insulated from competition. (Bergland, 1980)

Bergland then continued to outline the premises upon which his he based his decision to withdraw such funding:

> 1. The tax base that provides federal funds--including those spent on research--is a national base. Since revenue is collected from taxpaying citizens of every region, state, county and local community, it follows that the revenue collected should be spent on research that promises to benefit the broadest base of American citizens.
> 2. One of the key roles of government is to provide for the people what the people cannot be expectd to provide for themselves. Highways, public schools and hospitals, libraries, fire and crime protection...come immediately to mind, and, in this specific instance, research that is basic, sometimes long range, high risk in that it offers only limited prospects for an early return on investment, and anticipates or avoids counterproductive economic and social effects.
> 3. Under present economic conditions and national security considerations, it is even more imperative that federal dollars be spent frugally, wisely and equitably to bring maximum benefit to the maximum number of citizens and minimum disadvantage to the fewest possible. (Bergland, 1980)

Bergland also explained, "until recently, agricutlural research was evaluated almost exclusively in terms of what the research promised in the way of volume productivity gains". Too often, he said, potentially negative economic and social effects were not factored in to the evaluation. "What did this do", he asked. "It skewed cost-efficiency statistics and distorted perspective". And he warned, "if this is not remedied in the research evaluation process, it will surely handicap our ability

to meet changing national priorities".

The Land Grants & "Cutting Edge" Science

Following World War II, federal funding for military, space, national health, increased dramatically . During the 1960s, for example,the Russians' stunning success with Sputnik propelled and expanded public research funding for mathematics, physics, chemistry and engineering, and new super-agencies such as NASA were created. At this time, by comparison, the agricultural and bioloigcal sciences were "poor country cousins" when it came to federal funding. During the 1960s and 1970s, mounting concern with cancer and environmental pollution brought increased funding for the medical scienes. With the creation of the National Institutes of Health, the USDA began to loose part of its research turf as work on animal cell biology took on importance for medical and health reasons.

As new federal research thrusts were being initiated in space exploration, medicine and cancer research, criticism began to mount over the neglect of basic research in the biological sciences related to agriculture.

However, in many ways, the "neglect" of basic biological science in agriculture was not the fault of USDA or the

agricultural experiment station leadership. First of all, the land grants and the experiment stations were taking on new duties.

In 1982, William E. Marshall, than a biochemist working as technical director in the development sector of the General Foods Corporation, was recruited to review federally funded agricultural research for President Reagan's Task Force on Cost Control. What Marshall told Chemical & Engineering News that year about what he found, explains in part how the land grant and experiment station role expanded over time to include more tasks, which in effect, weakened their research thrust:

> What is clear from my studies is that the state agricultural experiment stations are in danger of losing their pre-eminent role in agricultural research. There are two reasons for this. As agribusiness grew, the research system became mature and a a result needed a lot of maintenance work. That was time and money taken away from research. (The stations) had to keep track of new pests, evaluate new fertilizers, and the like. That prevented growth of real research. Second, it was becoming evident that the future of agricultural advances lay in developments in plant biology, and the best work was being done outside the system... (Lepkowski, 1982)

Secondly, basic science was "neglected" because Congress did not fund it. Writing in the American Journal of Agricultural Economics in 1983, James Bonnen explained: "Congress has held research resources constant for 15 years, and since World War II has slowly politicized and destroyed the magnificent science

investment in the old USDA biological and physical science bureaus and the successor Agricultural Research Service." (Bonnen, 1983). Yet, criticism of USDA for not doing all it should do in basic science has been unrelenting for the last 15 years. The criticism is perhaps more properly aimed at Congress.

Between 1972-1976, the first critical reviews of USDA came from a number of quarters and led to a move in Congress to create a small competitive grants program in USDA. This program, intially funded at $15 million annually, has now reached $40 million a year, and is projected to reach $60 million annually in FY 1988. The competitive grants program allowed non-land grant universities to compete for USDA research funding.

The establishment of the competitive grants program in USDA was a significant historical and political development for the land grant system, and the political histroy surrounding this development, and subsequent moves to expand agricltural research funding <u>outside</u> of the land grant system, is very important to an understanding of where the system and its politics are today. And while space does not allow a detailed analysis of that story here, Appendix . contains a brief background on that fight and subsequent developments.

In addition to the establishment of the competitive grants program in USDA, there were subsequent proposals and reports,

such as the 1982 White House/Rockefeller Foundation "Winrock report", (also discussed in Appendix 5.), which recommeded less formula funding and more competitive grants funding, and closing down certain research stations. One idea even emerged for creating a National Institute of Agriculture modeled on the NIH.

These various proposals, however, were not without their own critics, some of whom argued that a nationalized, open-to-all competitive grants program in agriculture would favor the elite, well-staffed, well-endowed private universities and more prestigious land grants. The smaller land grants and out-of-the-way agricultural experiment stations--lacking the critical mass of molecular biology talent-- would not fare well in the competitive grant-making process. Others, citing the grant-making record under the NIH model-- where roughly 1 to 2 percent of the institutions get as much as 20 percent of the funding[7] --argued that such a system was not appropriate for agriculture, where regional variation and local problem-solving was more important.

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7 Interestingly, along these same lines, Senator Mark Hatfield noted in a letter to the editor of the Washington Post recently: "In practice, the peer review system has resulted in the top 20 research universities--all members of the Association of the American Universities--getting the bulk of federal research dollars year after year. A recent General Accounting Office study found that 16 of the top 20 universities receiving the most federal dollars in 1967 are still among the top 20 universities today. This is a system that allows few 'newcomers' any realistic hope of competing for large amounts of federal research dollars..."(Hatfield, 1987).

USDA Responds.

In responding to criticisim that it lacked a clear molecular biology effort or a special biotechnology thrust, the land grants, agricultural experiment stations, and USDA all began producing studies and special reports highlighting research that fit into the new categories. In April 1982, for example, the National Association of State Universities and Land-Grant Colleges created a Committee on Biotechnology to focus on policy issues, budget matters, industry/university relations, education and other matters. This committee began to issue yearly "progress reports" under the title: Emerging Biotechnologies in Agriculure: Issues and Policies..

By 1983, the state agricultural experiment stations were claiming to be inolved in some 579 biotechnology research projects funded at $50 million.

In August 1984, USDA established the Plant Gene Expresion Center at UC Berkeley, billed to become one of the world's largest biological technology centers. The federal government has already provided $4 million in start-up funds for the Center, and research will be conducted at the USDA Western Research Center in Albany, CA, located a few miles from the Berkeley campus. Under this program, researchers from UC Berkeley and USDA will join with industry scientists in agricultural biotech projects. In addition, because of this program, scientists at this center could receive several million dollars per year in

USDA

Biotechnology Research

($ in Millions)

	FY 1985	1986 Actual	FY 1987	FY 1988
ARS				
Plant Productivity	$10.2	$10.8	$15.5	16.6
Albany Gene Expression Center	(2.0)	(2.5)	(3.1)	(3.1)
Animal Productivity	8.8	8.3	12.9	14.4
Soil & Water Conservation	0.2	0.2	0.4	0.4
Commodity Conversion and Delivery	7.3	7.0	6.7	6.9
ARS Total	26.5	26.3	35.5	38.3
CSRS				
Hatch Act	12.2	11.6	11.6	12.1
Special Research Grants	3.4	3.4	3.4	- -
Competitive Research Grants	30.0	29.1	29.1	29.1
Forestry Competitive Grants	1.8	1.2	1.2	- -
All other	1.0	0.9	0.9	0.4
CSRS Total	48.4	46.2	46.2	41.6
Forest Service				
Intramural	1.8	2.0	2.8	2.9
USDA Total	76.7	74.5	84.5	82.8

USDA is placing increased emphasis on use of the new biotechnologies in forestry and agricultural research. Biotechnology is broadly defined to include the technologies of gene transfer (genetic engineering), cell and tissue cultures (asexual propagation), protoplast fusion (asexual genetic recombination from diverse species), and embryo manipulation and transfer.

competiitive grants money from USDA for biotechnology work.

By May 1986, CSRS reported that is was spending $45.9 million on agricultural biotechnology research.[8] Also in 1986, the USDA's Agricultural Research Service(ARS) explained:

> ...ARS does not consider biotechnology as a discipline or area of research. Thus, resources are allocated to specific high priority problems, and the biotechnology techniques or methodologies are used in research projects throughout much of the total program.
> Within ARS we consider biotechnology to include

8 CSRS broke down its 1986 biotech spending as follows:

Hatch Act	$11,623,000
McIntire-Stennis Cooperative Forestry	231,000
1890 Colleges & Tuskegee	210,000
Special Research Grants	3,098,000
Competitive Research Grants	28,614,000
Animal Health & Disease	514,000
Forestry Competitive Grants	1,684,000

(does not include state biotech funding)

CSRS also broke down its biotech research by number of projects, which it categorized as follows:

core biotech research	1,878 projects
fringe biotech research	593 projects
related biotech research	11 projects

(includes state-funded projects)

CSRS defines <u>core</u> biotech research as "projects that deal with recombinant DNA, tissue culture with selection, mutagenesis, all drug products, monoclonals, protoplasts, DNA probes, gene or proto sequence resecting, mapping, and similar manipulation; <u>fringe</u> biotech research as "projects dealing with tissue culture for propagation purposes only, chromatography, isozymes for speciation, classical serology (i.e., elisa, plant physiology, bio-chemistry, etc.); and <u>related</u> biotech research as projects which "include studies in the effects of biotechnology as a science, i.e., economy of biotechnology, sociological effects, etc.".

> recombinant DNA research; gene splicing, tissue, cell and embryo culture; protoplast fusion; and bioregulation of hormonal control of physiological and metabolic proceses. In 1986, ARS projects utilizing biotechnology techniques total about $27 million. These projects involve about 200 scientists who utilize biotechnology techniques. By the end of 1987, these totals will increase to about $35 million and 350 scientists. We do not have a good estimate on the proportion of funds directed toward understanding biological, chemical, or physical systems as opposed to the proportion directed toward development of a specific commercial product.

According to recent data obtained from USDA (Fulkerson, see Table 2.), ARS, CSRS and the Forest Service together spent $74.5 million on biotechnlogy research in 1986, with a projected $84.5 million in FY 1987, and $82.8 million in FY 1988.

A number of investigators have looked into USDA research spending in biotechnology in recent years, including GAO, the National Association of State Universities and Land Grant Colleges, and and the National Academy of Sciences. In its May 1987 study of agricultural biotechnolgy and strategies for competitiveness, NAS noted:

> Current expenditures for biotechnology research in the agricultural research system cannot be documented or compared with any precision, because few analyses of biotechnology research support were done until very recenlty. In addition, there is no widely accepted definition of biotechnology, which makes it difficult to establish clear-cut criteria for classifying such research... (NAS, 1987, p.77)

Although USDA and the agricultural experiment stations have

TABLE 3.

TABLE 3-8 A Comparison of Data on Funding Levels Available for FY84 and FY85 on Biotechnology and Agriculturally Related Biotechnology Research by Selected Sources

Sponsor	Amount (millions of dollars)
AGRICULTURALLY RELATED BIOTECHNOLOGY	
USDA[a]	
Agricultural Research Service	24.5
Cooperative State Research Service:	
Competitive Research Grants Office	30.0
Hatch Act and Special Grants	18.4
SAES (nonfederal support)[b]	
State funding	17.3
Industry	5.6
Private industry[c]	150.0
ALL BIOTECHNOLOGY[a]	
EPA	1.5
FDA	2.6
NIH	1,849.5
NSF	81.6

NOTE: EPA = Environmental Protection Agency; FDA = Food and Drug Administration; and SAES = State Agricultural Experiment Stations.

[a]FY85. Competitive Research Grants Office funding includes both specific biotechnology grants and additional biotechnology-related research covered by its other grants. Funding by non-USDA federal agencies may include some agriculturally related biotechnology research. SOURCE: Government Accounting Office, 1986.

[b]FY84 data.

[c]Estimate based on data from the Agricultural Research Institute, 1985. A Survey of U.S. Agricultural Research by Private Industry III. Bethesda, Md.

SOURCE: National Association of State Universities and Land-Grant Colleges, 1985.

26-A

Table 4.

TABLE 3-7 State Agricultural Experiment Station and Veterinary College-Sponsored Biotechnology Research (millions of dollars) for FY84[a]

Source of Funding	Biotechnology Research	Total Agricultural Research	Percentage of Total Agricultural Research that is Biotechnology Research
Competitive Research Grants Office	2.8	11.6	23.9
All other USDA funds	7.9	173.6	4.6
Other federal agencies	13.6	109.1	12.5
State agencies	17.3	551.2	3.1
Industry	5.6	86.3	6.5
Total	47.2[b]	931.8	5.1

[a] Relates to the 495 research projects discussed in the Government Accounting Office (GAO) Report; data for FY84.

[b] This figure does not include an estimated $500,000 reported to the GAO by the North Dakota Agricultural Experiment Station or $1,693 reported by the Ohio Experiment Station. These two stations, although providing GAO with a total figure for their biotechnology research, did not identify the specific sources of that funding and GAO, therefore, excluded the amounts from the table.

SOURCE: General Accounting Office, 1985. Biotechnology: The U.S. Department of Agriculture's Biotechnology Research Efforts. Washington, D.C. (GAO/RCED-86-39-BR).

gone to some lengths to move forward in biotechnology research, there are mounting pressures to do more, both within the system and from outside the system. Today, there are new special programs being proposed for agricultural biotechnology research that expand upon the competitive grants approach,[9] and in other cases, entirely new programs at the state and federal levels. Most recently, the White House has proposed a new initiative for plant science research, which continues the trend of moving agricultural research away from the land grant complex. Congress is also considering new measures, such as a bill recently

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9 For example, in May 1987, the National Academy of Sciences (NAS) released a report entitled "Agriculutral Biotechnology: Strategies for National Competitiveness", which among other things, recommended substantial increase in competitive grants funding and re-directed USDA spending:

> It is logical that primary funding for agricultural biotechnology should be achieved through the USDA. Unfortunetly, funding for both intramural and extramural basic research within USDA is well below that of other federal agencies. USDA has recognized the need to support basic research and is attempting to do so, albeit not as rapidly as might be optimal. Funding increases are needed. Allocation of new and even redirected funding should be based principally on competitive peer and merit review.
>
> Any increase in funding at USDA should not come a the expense of appropriations to other federal agencies that support biological research relevant to agriculture. This is because it is not always clear where innovation applicable to agricultural biotechnology might arise. However, some existing research program funds should be redirected within USDA to heighten the priority given to biotechnology...

The NAS study recommends that competitive grants by all agencies in the federal government for biotechnology research related to agriculture "total upwards of $500 million annually, a level that could support 3,000 active scientists". And NAS recommends that this level of support should be achieved by 1990, "primarily through competitive grants administered by USDA and the National Science Foundation". (NAS, 1987).

introduced by Senator Tom Harkin (D-IA). These two programs are described in more detail in Appendix 4.

* * * * *

There seems to be a growing tendency in the public sector funding of agricultural biotechnology research to purposely "end run" the existing USDA-led land grant/ag experimnent station system with new programs specifically designed and structured to encourage research at non-land grant institutions. While some amount of new initiatives may be needed to galvinize focused research in molecular biology within the USDA system, it would be unfortunate and inefficient to by-pass researchers and research infrastructure that have been working reasonably well in the biological and agricultural sciences for many years.

Private-Sector Agricultural Research Spending

Private companies investing money and manpower in agricultural research is a relatively recent phenomenon in U.S. history. Historically, for the most part, that task has been left to the USDA and the land grant system. In fact, little data are available on company-initiated agricultural research expenditures much before 1965. A 1985 survey of private sector investment in basic agricultural research conducted by the Agricultural Research Institute found that such investment rose from $460 million in 1965 to $2.1 billion in 1983. (ARI, 1985).

Biotechnology and the changes in patenting law have figured prominantly in this change, but they have not been the only reasons. The projected growth in world food markets, and in the supplements needed to make agriculture productive, have also been factors. And in some cases, for example, corporations that acquired seed companies prior to 1970, such as Upjohn, played an important role in moving patent legislation to the foreground.

But since 1970, developments in the patenting arena have contributed to an increased private sector interest in plant and animal science, and a corollary de-emphasis in some areas of public-sector plant and animal research. These developments include: 1) the Plant Variety Protection Act of 1970, extending patent-like "variety protection" to seed-propagated plants; 2) the U.S. Supreme Court's Diamond v. Chakrabarty ruling of June 1980 allowing the patenting of man-made microorganisms; 3) the October 1985 U.S. Patent Office ruling in Ex parte Hibberd, allowing open-pollinated plants to be patented under the general patent statues; and 4) the April 1987 U.S. Board of Patent Appeals ruling allowing man-made, or genetically improved "multicellular organisms, including animals" to be patented.

Generally, private sector investments prompted by the new opportunites in plant genetics and molecular biology began earlier than those in the public sector. That is, corporate and investor behavior in reaction to "biotechnology", and agricultural biotechnology, has been much more apparent in the

private sector than the recent reorientation effort within the USDA system.

Although USDA and some USDA-scientists were "out front" in terms of visibility in such popularly reported developments like the "sunbean" and a genetically engineered hoof and mouth vaccine in the early 1980s, budget-wise, "biotechnology" per se did not begin to appear as a discreet category of research activity until about 1983.

Meanwhile, in the private sector, during the late 1970s and early 1980s, investment in biotechnology research, and in the infrastructure needed to deliver the new products of agricultural biotechnology, was being expressed in a number of ways, including: the acquisition of seed companies, the formation of new biotechnology companies, research and development limited partnerships, initial public offerings on Wall Street, university contracting, and in-house corporate investments.

A 1981 Forbes article reveiwing the agricultural reseaarch of 10 major U.S. companies turned up some estimates of annual agricultural research expenditures in the $20-to-$80-million-range (see Table 5). That survey also indicated that these companies were investigating basic areas such as nitrogen fixation and photosynthesis, as well as more applied areas such as soybean hybridization and the use of plant growth regulators. (Tamarkin, 1981).

TABLE 5

Agricultural R&D Expenditures By Some Major Corporations

Company	Area of Long-term Agricultural Research	Agricultural R&D (millions)[1/]	Total R&D (millions)[2/]
Allied Chemical	nitrogen fixation	$30	$ 69
American Cynamid	plant growth regulants	73	124
Dow Chemical	photosynthesis	40	268
DuPont	nitrogen fixation	42	415
Eli Lilly	recombinant DNA	63	174
Merck	plant genetics	24	188
Monsanto	plant growth regulants	84	173
Pfizer	plant genetics	22	137
Upjohn	soybean hybrids	26	130
Union Carbide	plant growth regulants	46	165

Source: Tamarkin, Bob, "The Growth Industry," Forbes, March 2, 1981, p. 94.

1/ Estimated.

2/ Based on latest available figures.

According to Will Carpenter, general manager of technology for the Monsanto Agricultural Products Company, "Monsanto has an annual agricultural research expense budget of about $200 million and 1,000 people". (ESCOP, Research Perspectives, 1985, p. 35). Monsanto's investments in biotechnology are quite extensive, and have been building over a decade or more (Table 6). But other companies have made similar capital and research invesments, betting on biotechnology. Today, companies such as Ciba Geigy, Du Pont, ICI, W.R.Grace, Lubrizol and others continue to make substantial investments in agricultural biotechnology research. (see for example, Jack Doyle, Altered Harvest, (Viking-Penguin), 1985, appendix of companies).

* * * * * *

"Land-grant universities don't sell their souls to private industry--they willingly give them away".
- Prof. Harold Breimyer, emeritus
University of Missouri
Wall Street Journal, 1987 (Farney)

Corporate Investment in University Research

A number of agricultural biotechnology companies, as well as major corporations, have also made, and continue to make, research contracts and other agreements with university researchers (see Table 7). Some of these companies have enlisted the services of university scientists to serve on scientific

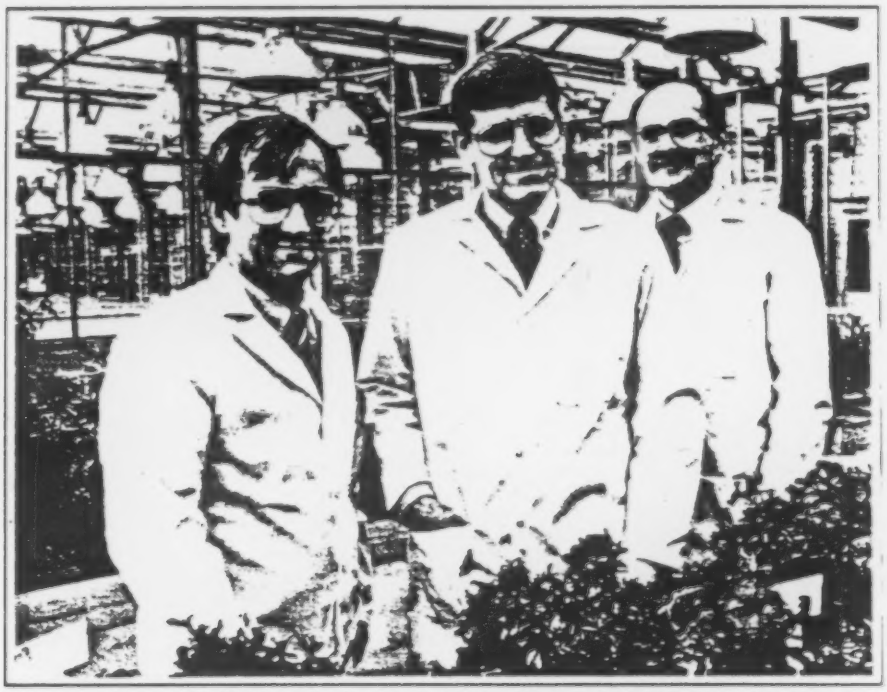
Table 6.

MONSANTO & BIOTECHNOLOGY

1969	- acquires Farmers Hybrid Co., a cattle & hog breeding firm
1974	- 12 yr., $23 million R & D contract with Harvard
1978	- takes a small equity position in Genentech
1980	- $100 million to form an animal nutrition unit focusing on new sources of animal feeds & health products using genetic engineering
1981	- purchases $20 million of preferred stock in Biogen
March 1981	- announces with Genentech the development of a genetically-engineered "bovine growth homone" & the formation of a joint program with Genentech to produce growth hormones for hogs & cows
March 1982	- acquires hybrid wheat research program from DeKalb AgResearch, Inc.; forms seed subsidiary named Hybritech Seed Internation, Inc.
June 1982	- 5 yr, $23.5 million research contract w/ Washington University
Jan 1983	- Monsanto scientists successfully insert a bacterial gene into plant cells; gene expressed in plant cell
April 1983	- acquires Jacob Hartz Seed Co. of Stuttgart, Ark.,a soybean seed company
Dec 1983	- $1.8 million to Oxford University for 5-yr research contract for work on sugar molecules
Oct 1984	- opens new $200 million Life Sciences Research Center in St. Louis
Dec 1984	- announces it will apply to EPA for permission to field test a genetically engineered microbial pesticide
1985	- acquires G.D.Searle & Co. for $2.7 billion
May 1986	- $26 million to Washington University, extending research collaboration to 1990.

Source: compiled by the Environmental Policy Institute, Wash.,DC

WORKING HAND IN HAND WITH NATURE



Monsanto scientists Robert Horsch, Stephen Rogers and Robert Fraley have won the Company's 1986 Charles A. Thomas & Carroll A. Hochwalt Award. The award, which carries a silver medallion and a $40,000 prize, is reserved for innovative basic science of the highest calibre.

Imagine a plant able to protect itself from insects by producing its own natural insecticide. Or one resistant to disease or drought. Or resistant to safe, biodegradable herbicides. Imagine how plants like these would improve the economics and efficiency of farming.

Monsanto scientists Robert Fraley, Robert Horsch and Stephen Rogers set out just six years ago to discover a way to transfer useful qualities like these into crop plants—using genetic engineering. The result: they were among the first to develop a method for transferring desired genes into plants. This method has won international recognition among industrial and academic scientists alike.

Because of the pioneering work of these three men and their colleagues at several universities, Monsanto has developed plants which are resistant to certain diseases and to Roundup® herbicide.

In announcing the awards, Howard A. Schneiderman, Senior Vice President, Research & Development, said: "Innovative research like this will help make farming a more reliable, more profitable business. Its aim is to make farming less subject to pests and require less chemicals, fertilizers and tilling. Genetic engineering will help increase the productive efficiency and competitiveness of the American farmer as we have never been able to before."

Monsanto salutes these innovators—and the many other scientists and engineers in our research community—who are challenging tomorrow, every day.

Monsanto

We challenge tomorrow, every day.

Roundup® is a registered trademark of Monsanto Company

Plan to participate in *National Science & Technology Week* '87 April 5-11, coordinated by the National Science Foundation.

advisory boards.

TABLE 7

CORPORATE RESEARCH GRANTS TO UNIVERSITIES
FOR AGRICULTURAL GENETICS / BIOTECHNOLOGY RESEARCH

Company	University	Amount & Purpose
1981		
Granada Corp.	Texas A & M	$279,140 to D. Kraemer for improving the efficiency of embryo transfer in cattle (1981-84)
1982		
Agrignetics Corp.	Purdue	$904,388 to T.K. Hodges (Botany) for development of a tissue culture facility & project for agronomic crops (FY 82)
Busch Agricultural Resources, Inc.	Univ. of Ark.	$10,000 to R.H.Dilday for rice breeding, genetics & evaluation (FY 82)
Choc. Manufacturers Association	Purdue	$190,000 to J.Janick & P. Hasegawa (Hort.) for in vitro production of cocoa (FY 82)
Cotton, Inc.	Univ. of Arkansas	$15,000 to B.A.Waddle (Agron) for development of early maturing cotton, Gossypium Hirsutum L., genotypes for Eastern Arkansas (FY 82)
Dow Chemical	Univ. of Arkansas	$6,510 to J.T.Batchelor (AES) for nitrification inhibitors research (FY 82)
Dow Chemical	Purdue	$2,500 to L.Schweitzer (Agron) for soybean plant regulation with DOW CO 319X

		(FY 82)
Dow Chemical	Purdue	$10,000 to D.B.Mengel (Agron) for nitrogen fertilization of corn & wheat (FY 82)
Monsanto	Rockefeller Univ.	$4 million research grant, including research on the regulation of plant genes involved in photosynthesis
North American Plant Breeders	Purdue	$11,400 to L.E.Sommers (Agron) for evaluation of alfalfa & red clover varieties (FY 82)
W.R. Grace	M.I.T.	5-yr., $8.5 million grant for microbiology research program
<u>1983</u>		
Agrigenetics	Cornell	$25,000 for disease resistance & cytoplasmic male sterility in corn
Agrigenetics	Purdue	$389,000 research contract with Thomas K. Hodges (Botany Dept.) for development of a tissue culture facility & research project for agronomic crops
Agrigenetics	Purdue	$275,000 research contract with Brian Larkins (Botany Dept.) for genetic engineering research of seed protein genes
American Cyanamid	Cornell	$30,000 for growth hormone in lactating dairy cows
Biogen	Purdue	$16,005 research contract with D.P. Gustafson (Vet. Med.) for experimentation with uses of interferon in animals.

Bayer Chemical Co.	Cornell	$110,000 for chemical & biological interactions between insects, plants, and microorganisms
Calif. Biotech.	UCLA	sponsoring research by Dr. Michael Karin (Microbiology) to manipulate the genes for growth & other hormones in domestic animals; includes germ-line modification
Calif. Biotech.	Cornell	sponsoring research of Drs. Dorothy F. Holmes & James H. Gillespie (Vet. Med) to produce a modified live virus vaccine for an equine influenza
Calif. Biotech.	Cornell	sponsoring research of scientists under Dr. Edward J. Dubovi (Vet. Med.) to develop diagnostic tests for infectious bovine rhinotracheitis virus, equine rhinopneumonitis virus, and bovine diarrhea virus.
Dow Chemical	U. of Arkansas	$6,000 grant to P.A. Counce for research on nitrification inhibitors in wheat
Dow	Purdue	$4,000 research contract with D. Mengel (Agronomy) for research on nitrogen fixation.
Eli Lilly	Purdue	$3,000 contract with G.E. Moss (Animal Sci.) for research dealing with the effect of various compounds on growth hormone release
Kodak	Cornell	$64,200 for stimulation of microbial growth, protein protection, and amino acid bypass for ruminant animals

Monsanto	Cornell	$69,574 for milk production by dairy cows injected with biosynthetic bovine growth hormone
Monsanto	Cornell	$197,611 for milk production from Holstein-Fresian cows injected with recombianant or pituitary-extracted bovine growth hormone
Native Plants	Purdue	$120,000 contract with A. Handa & S. Weller (Hort.) for evaluation exploitation of genetic variability & adventitious potato plants derived from tomato culture (FY 83)
Nestle	Cornell	$44,000 for varietal screening of zucchini in order to improve texture, appearance & flavor
Pioneer Hi-Bred	Cornell	$92,140 for construction of gene-cloning vectors for fungal pathogens
Standard Oil (Ohio)	U. of Illinois	$2 million grant to promote long-range research to improve food production through genetic engineering, primarily in corn/soybeans.
Tysons Foods	Univ. of Arkansas	$3,000 to L.D.Andrews (An. Sci.) for broiler breeder research (FY 83)
1984		
Agway, Inc.	Cornell	$75,000 for forage breeding
Agrigenetics	Purdue	$365,997 to T.K.Hodges (Botany) for devlopment of a tissue culture facility & project for agronomic crops
American Cyanamid	Cornell	$16,423 for validation of a radioreceptor assay for measuring recombinant-derived bovine growth

		hormone
Asgrow Seed Co. (Upjohn)	Purdue	$13,435 to J.R.Wilcox (Agron) for soybean research
Biogen, Inc.	Purdue	$12,933 to D.P.Gustafson (Vet Med) for experimental uses of interferons in animals
Ciba-Geigy	Penn State	supporting research of Jean-Marc Bollag (Soil Microbiology), on "Microbial Control of Soil Pollution"
Hershey Foods	Penn State	supporting research of Paul J. Fritz (Pharm.) on "The Molecular Biology of the Cocoa Plant"
Hubbard Farms (Merck & Co.)	Cornell	$6,170 for studies of sex-linked dwarfing genes in broilers
Int'l Minerals & Chemicals Corp.	Purdue	$31,420 to F.E.Regnier (Bchm) for preparative ion exchange chromatography of proteins
Monsanto	Purdue	$30,000 to P.E.Dunn (Entm) for insect biochemistry (FY 84)
Monsanto	Cornell	$30,000 for research & development of bovine somatotropin
Nestle	Cornell	$44,000 for research on bittnerness in squash
North America Plant Breeders	Purdue	$15,526 to K.D.Johnson (Agron) for nitrogen studies with alfalfa & red clover
Pioneer Hi-Bred	Penn State	supporting research of Jack C. Shannon (Hort. Phys.) on "Study of Physiological Factors Possibly Regulating Grain Yield in Maize"

Popcorn Institute	Purdue	$23,000 to R.B.Ashman (Btny) for improving popcorn hybrids
Quaker Oats	Purdue	$8,372 to H.W.Ohm (Agron) for development of Oats that are resistant to Barley Yellow Dwarf Virus
Quaker Oats	Purdue	$12,460 to H.W.Ohm (Agron) for improving the competitive ability of oats in Indiana & other oats-producing states in the Midwest
Rohm & Haas	Univ. of Penn.	$1 million gift toward the Plant Science Institute, which will do basic research in plant development, photosynthesis, plant disease & plant reproduction
Shell	Purdue	$5,000 to H.W.Ohm (Agron) for work with chemical hybridizing agent in soft red winter wheat
Showalter Trust	Purdue	$36,000 to R.A.Bressan (Hort) for development of tissue culture systems to produce important plant secondary products
Stauffer Chemical	Purdue	$2,000 to D.M.Huber (Botny) for soil microorganism research
SOHIO	Penn State	supporting research of S. Edward Stevens, Jr., (Micro. & Molecular Bio.) on "Algal Genetics, Physiology, and Photosynthesis".
Upjohn	Purdue	$2,000 to E.C.Tigchelaar (Hort) for Muskmelon breeding program
Weyerhaeuser	Cornell	$30,000 for cryopreservation of conifer buds & cotyledons

1985

Agrigenetics	Purdue	$642,135 to T.K.Hodges (Botany) for development of a tissue culture facility & project for agronomic crops (FY 85)
Agrigenetics	Purdue	$275,000 to B. Larkins (Botany) for genetic engineering seed protein genes (FY 85)
Agrigenetics	Cornell	$125,845 to M.R.Hanson for tomato hybridization through cell culture
American Cyanamid	Cornell	$32,535 to R.D.Boyd for research onexogenous porcine growth hormone on lactation performace in sows
Crow's Hybrid Corn Co.	Cornell	$15,000 to V.Gracen for tissue culture regeneration
Eli Lilly & Co.	Purdue	$34,696 to H.W. Ohm (Agron) for wheat genetics research (FY 85)
Eli Lilly & Co.	Purdue	$24,982 to L.L.Murdock (Entm) for research on digestive proteinases & inhibitors in Colorado potato beetle, corn rootworm, & boll weevil (FY 85)
Hoffman-LaRoche	Purdue	$13,854 to D.P.Gustafson (Vet Micro) for evaluation of interferons in pigs against psuedorabies virus (FY 85)
Kodak	Purdue	$10,000 to T.W.Perry (An. Sci.) for research on protected amino acids for beef cattle (FY 85)
Kodak	Cornell	$30,010 to S.A.Zahler for research on controllable plasmids for Bacillus

Land O'Lakes	Iowa State Univ.	funding research to increase nitrogen fixation in soybeans
Martin Marietta	Cornell	$106,103 to D.J.Lathwell for screening & selection of herbaceous species for biomass production in the Midwest/Lake States
Miles Labs(Bayer)	Purdue	$5,000 to T.W.Perry (An. Sci.) for value of inoculation of ensiled high-moisture corn with lactic acid producing bacteria (FY 85)
Monsanto	Purdue	$10,000 to P.E. Dunn (Ent.) for research on insect biochemistry (FY 85)
Monsanto	Purdue	$9,000 to P.E.Dunn (Ent.) for research in mode of action of Bt. toxin (FY 85)
Monsanto	Purdue	$10,000 to R.L.Somerville (Biochem.) for research on genetic regulatory mechanisms (FY 85)
Northrup King (Sandoz)	Cornell	$5,000 to V.Gracen for tissue culture regeneration
Pfizer, Inc.	Purdue	$20,000 to T.R.Cline (An. Sci.). ionophore research in swine.
Quaker Oats	Purdue	$13,000 to H.W.Ohm (Agron), yellow dwarf resistance in oats.
Quaker Oats	Purdue	$9,000 to F.L. Patterson (Agron) for oat improvement.
S.D.S. Biotech	Purdue	$5,570 to V.B.Mayrose (An. Sci.), efficacy of four growth promotant regimes for growing-finishing swine
Standard Oil Co.	Cornell	$25,477 to E.D.Earle for isolation & regeneration of meristematic corn

Upjohn	Purdue	$17,445 to J.A.Patterson (An. Sci) for development of a defined culture system for studying bacterial interactions involved in plant polysaccharide utilization (FY 85)
1986		
Eli Lilly & Co.	Texas A & M	$300,000 to ongoing research on viral pesticides (1986 & 1987)

Source: Compiled by the Environmental Policy Institute, Wash,DC from various agricultural experiment station bulletins, annual reports, and news accounts.

For new biotechnology companies starting out in the early 1980s, and those who continue to make public offerings on Wall Street, the "university connection" -- whether through identified research contracts or named science advisors--is an important asset, or credibility factor, for attracting investors.[10] Sponsored university research projects and scientific advisory boards are often listed in prospectuses and limited partnership documents. And for both biotechnology companies and major corporations, investing in a university research project can pay off, either in terms of knowldege useful for making products, or in actual product rights resulting from the research arrangement.

10 For example, in one of its first limited partnership offerings, the Agrigenetics Corporation listed scientists it had research contracts with at the following universities or research centers: Columbia, the Charles F. Kettering Research Lboratories, the University of Pennsylvania, Cornell, the University of Colorado, the University of Virginia, the University of Tennessee, Purdue, the Boyce Thompson Institute for Plant Research, North Carolina State University, the University of California, Oregon State University, and the University of Illinois.

INDUSTRIAL GRANTS, CONTRIBUTIONS* TO THE
AGRICULTURAL EXPERIMENT STATION, PURDUE UNIVERSITY
FY 1981 - FY 1985

Year	Amount	Percent
1980	$452,444	1.9
1981	$600,015	2.2
1982	$923,477	3.2
1983	$1,446,957	4.8
1984	$1,733,597	5.5
1985	$1,766,820	5.5

Source: compiled by the Environmental Policy Institute, Washington, D.C. and adapted from, "Director's Financial Report For Agricultural Experiment Station", Fiscal Year 1982-83, Station Bulletin #430, p. 60; and Fiscal Year 1984-85, Station Bulletin #482, p. 46.

*Note: Does not include "cash contributions for sponsored programs" which include corporate and other private sector contributions, such as those from individuals and private foundations. Yet the corporate share in this category could be substantial and would increase the amounts and the pecentage share in the above listing.

In addition to the companies looking for university projects to invest in, the universities themselves have become quite interested in attracting private sector funds to their biotechnology programs, particularly when federal or state money cannot be found. At Penn State, private sector contributions to its 1984 biotechnology program constituted some $627,000, or 9.6 percent of total funds--a figure three times the national average. But officials there expect that figure to grow: "...program associates expect that the expertise and research interests of the faculty... will attract a two- or threefold increase in private support over the years to come". (Penn State, 1984).

Corporate money for research generally at universities has been increasing in recent years,[11] and agricultural research is not exception. For example, industrial grants and contributions to research at Purdue University's Agricultural Experiment Station have nearly tripled in recent years, increasing from $600,000 or 2.2 percent of total funding in FY 1981, to $1,766,820 or 5.5 percent in FY 1985, and this amount does not include cash contributions and gifts. (Purdue University, 1985).

11 In 1956, business provided colleges and universities with about 13% of total gifts; now it's nearly one quarter. Since 1976, total giving to colleges has tripled, but business contributions have risen fourfold. In the academic year 1984-85, corporations gave universities more money than the entire national alumini body. In 1985-86 corporations gave a total of $1.7 billion to American universities. Of this share, research arrangements between corporations and American universities constitute more than one-third, now running at some $600 million annually.

But how much does a dollar from the private sector actually buy in the public sector? Some analysts have estimated that an industrial sponsor can obtain from five to ten dollars' worth of publicly supported research for each dollar of grant support they give. (Barnett, 1980). In addition, others have argued that while the actual corporate share of any one research project may not be dominant source of funds, it is not so much the proportion of funds that matters, as it is the way in which such funds influence research priorities and how corporate money is leveraged in specific research areas to achieve commercial ends. (Strange, et.al.,1982).

Moreover, in biotechnology research, interdisciplinary teams and longer term projects are being organized for funding, incorporating money from several major sources. Grants for these projects tend to be larger than those of the past, and in some cases are very large, encompassing whole departments.

In research projects such as the one described in Table 8 who has control over the project, how are research goals determined, and how are benefits allocated?

Table 8

TEXAS A & M--MOLECULAR TRANSFORMATION OF PLANTS
(sorghum, sunflower & wheat)

Researchers: Dr. Timothy Hall

Project Description: project includes study and indentification of the genetics controlling storage seed protein in sunflower and sorghum; project also includes research to enable transfer of gene responsible for gluten in wheat to sorghum

Contrributors	Amount
Texas Advanced Technology Project	$250,000
NSF	$261,000
USDA	$140,000
NIH	$149,748
Rhone-Poulenc	$116,000

Source: Texas Agricultural Experiment Station

In projects such as these, the goals of each of the participants may be quite different, and in total, add up to efforts that are not efficient in terms of the public's investment, or favor a purely commercial purpose.

If industrial participants in publicly funded research projects leave those projects with knowledge or material they then use to develop propreitary products which are marketed at patent-protected price levels, is the public really getting the fair return it bargained for in sponsoring the research?

At some universities, however, corporate research funds are co-mingled with other funds, and it is difficult to discern which source has control of a particular project, how much any one source influences the research underway, or which source walks away with the fruits of the research (See for example, Table and Table).

In the case of the funding of the research of Brian

Larkins at Purdue University, for example, it is clear that the Agrigenetics Corporation (a subsidiary of Lubrizol) has been the dominant funding source for the FY 1982-1986 period, contributing more than $1.6 million, approximately $500,000 more than the combined federal agency funding during that same period.

But how are the results of this research reported ? Can the results, in fact, be separated ? Is there an intended interplay between the research projects ? And, if so, how much of the research is the public entitled to ?

TABLE 9

SOURCES OF FUNDING FOR THE RESEARCH OF B. LARKINS
DEPT. OF BOTANY & PLANT PATHOLOGY
PURDUE UNIVERSITY--FY 1982 THRU FY 1986

FY 82		
Agrigenetics Corp.	$300,750	for genetic engineering seed protein genes
NSF	$218,975	analysis of zein protein gene expression during maize endosperm development
FY 83		
Agrigenetics Corp.	$275,000	for genetic engineering seed protein genes
DOE	$120,000	studies on structure & expression of genes in higher plants
NSF	$100,000	analysis of zein gene organizaiton & expression in maize
USDA	$42,200	analysis of the differential synthesis of oat storage proteins

FY 84		
Agrigenetics Corp.	$441,697	for genetic engineering seed protein genes
Agrigenetics Corp.	$84,124	genetic engineering of genes with maize transposable elements (jointly with T.K. Hodges, Botany)
NSF	$70,000	analysis of zein organization & expression in maize
FY 85		
Agrigenetics Corp.	$275,000	for genetic engineering seed protein genes
NSF	$75,000	analysis of zein gene organization & expression in maize
NSF	$109,000	planning grant for an industry/univ. cooperative research center in plant molecular biology & biochemistry
FY 86		
Agrigenetics Corp.	$255,305	for genetic engineering seed protein genes
Public Health Service	$125,592	analysis of zein gene expression
USDA	$130,000	analysis of seed globulin genes & their expression in cereals
Weizmann Institute	$23,000	American Committee for Weizmann Institute of Science, Inc.
Weizmann Institute	$1,162	research fellowship

Source: compiled by the Environmental Policy Institute, Wash., D.C.; adapted from Annual Reports of the Agricultural Experiment Station, Purdue University, West Lafayette, Indiana, incorporating Station Bulletins #'s 390, 430,

463, 482, and 505, FY 1982 thru FY 1986.

Biotechnology-- with its potential and its controversy--has brought a renewed sense of public interest in what role government research agencies and publicly-supported universities should play and are playing in the advacement of this new technology. In recent years, there have been university/indutrial forums, numerous journal articles and commentaries, and at least one congressional hearing that have focused on the proper role of publicly supported intitutions in the advance of the new biology. Little satisfactory resolution or definitive guidelines have emerged from this debate to date, except for case-by-case institutional guidelines.

While many of today's concerns over the private sector's influence on public sector agricultural research are similar to those of the past-- including concerns about research agenda, beneficiaries of the research, conflicts of interest, etc.--there are a couple of differences and new dimensions.

First, initial private sector inroads in the biological sciences came at a time when the levels of public funding were being restricted, particulalry in the early 1980s. Second, patenting in the seed, animal and microbial realms is new, and has had an impact on the conduct of research (particulalry scientific exchange) within the public sector, as well as being viewed as a revenue source by university administrators. Third,

in the last few years the size of some corporate research grants to universities has been larger than any individual grants ever before, some made over multiple year periods or made by several corporations focused on one particular institute. And fourth, university/industry/government cooperation, in the form of jointly-funded research, consortia, and special institutes -- all in the name of improving the U.S. competitive position -- is a new and powerful public policy development.

Agribusiness Consolidation & Its Impact on Agricultural Research

Agribusiness in the United States today is changing. In a word, it is becoming bigger. It is also becoming more horizontally and vertically integrated, thanks in part to biotechnology.[12] Mergers and acquisitions throughout the food,

12 In a speech before the Industrial Biotechnology Association this past October in San Francisco, Roger Salquist, Chief Executive Officer for the biotechnology company Calgene, asked his audience: "... who are the names that you think of when it comes to agricultural biotechnology?" "It's not necessarily the farmers", he said. "It's the Campbell soup companies, the Kraft Food Co., the R.J. Reynolds Co." (Salquist, 1986). These are the interests who are investing in and who are going to commercialize biotechnology in agricutlure in Roger Salquist's view.

What's going to happen with biotechnology according to Salquist, is that the major processing companies that used to buy their agricultural crops on the open commodity markets, are now going to stake out a proprietary interest in those crops because they can command the genes in those crops for specific ends:

> Look at the major processors now; they all have their own breeding programs. In essense, they're creating their own tomatos to have the specific traits they want to have for higher value. And, you're going to see that across the board--from brewing companies, to food

meat packing, seed, pesticide, fertilizer, and animal health sectors are resulting in corporations with tremendous influence over agricultural productivity, and many of these firms are now involved in biotechnology research (for a sector-by-sector sampling of some of the agribusiness mergers and acquisitions that have occurred in recent years, see Appendix___; see also Doyle, 1985).

As the agribusiness sector moves into fewer and fewer hands, and the global share of each company's market grows larger and larger, there will be an increasing emphasis on agricultural research, whether in-house, at universities, or in an affiliate biotech company. Corporate agricultural research programs will be driven by large-market product considerations, and as such, may be oriented to what will work and can be sold throughout the Temperate Zone, rather than what might be appropriate for the soils and ecology of northern Missouri.

Larger, fewer agribusiness companies operating throughout the agricultural economy will also undoubtedly mean larger grants to universities, and a more pointed influence in federal agricultural research funding, national science policy, and

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companies, to tobacco companies. They're engineering products and integrating backwards. (Salquist, 1986).

Indeed, the Congressional Office of Technology Assessment is inclined to agree with Salquist on this last point, noting it its March 1986 report, "Technology, Public Policy, and the Changing Structure of American Agriculture", that contracting and vertical integration in agriculture and food production are likely to increase with biotechnology because of the control it offers over the genetic elements of production (OTA, 1986).

national farm policy. Through such political influence, and its own product-oriented research, private-sector food and agricultural companies will become an even more dominant force in determining the agricultural research agenda--both public and private--than they are today.

If one of the purposes of a federally funded agricultural research system is to maintain and enhance a competitive farm and food supply sector, then it behooves our political leaders to require that USDA research meet such a goal. Presently, however, this aspect of domestic competitiveness and equity on behalf of all farmers and consumers, seems to be lacking in our agricultural research system. Congress should move to re-instate this aspect of our agricultural research system by requiring USDA to make a comprehensive evaluation and report of how its research programs enhance competition in the food and farm supply sectors, looking particularly at how research in biotechnology might diminish or expand such competition.

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"Farmers are smart people. And when things get tough, they turn to technology. And what they're going to do in the future to restore profitabililty and the vitality of their industry is turn to technology. And the technology that's going to make it happen is biotechnology."

- Roger Salquist, CEO
Calgene, Inc.

CASE STUDY: BOVINE GROWTH HORMONE IN THE DAIRY INDUSTRY

Bovine growth hormone (bGH), or bovine somatotropin, is a hormone that governs lactation and metabolic rates in dairy cows. It is produced naturally in the pituitary glands of the animal, but only in trace amounts, which has made its isolation and extraction for commercial purposes prohibitively expensive. But all that has changed with genetic engineering, and the ability to code multiplying microbes with the gene to produce the trait in huge quantitites.

bGH increases the cow's metabolism, and increases the flow of blood through the cow's mammary glands, resulting in greater output of milk. When injected into dairy cows at a rate of about 1/1000th of an ounce per day, bovine growth hormone will raise milk yields by as much as 40 percent per cow, but more likely, by about 25 to 30 percent per well-managed herd. When agricultural economists began to look at what this would mean for the dairy sector as a whole, they found that the number of dairy cows nationwide would need to be reduced by as much as one third, while the number of dairy farms would need to be reduced by 25 to 40 percent.

"It's going to be an awsome production increase", said Robert J. Kalter, chairman of Cornell's Agricultural Economics Department in an October 1985 New York Times article. "You inject one day and three days later you get the result--in your milk

bucket". (Serrin, 1985)

And the impact of bGH is not projected to fall evenly across all kinds of dairy farms. Large operations would make out better than smaller operators, and there would also be some differences among regions, with the "family farm" dairy belt from Minnesota to Vermont region, generlaly yielding ground to the newer "sun belt" 2,000 to 3,000-head dairies equipped with the latest cpital equipment, stress-free environments, and computer-assisted feed formulation.

Bgh will require "higher octane" feed ration. But overall, says USDA's Richard Fallert of the Economic Research Service, less grain will be needed "because we'll need fewer animals for a given volume of milk" (Andrews, 1986).

Public & Farmer Concerns

With the announced plans to develop and commercialize bGH, there has been farmer, Congresssional and public reaction, including the following:

- farmer protests in Wisconsin, with picketing of publicly and privately-sponsored university research on the hormone;

- a proposed national consumer boycott of BGh-produced milk by the Foundation on Economic Trends;

- a June 1986 Congressional hearing on BGh concerned with USDA's role in sponsoring BGh research, the product's impact on family farmers, and its impact on the dairy price support program;

- two bills introduced in the U.S. House of Representative in 1986 by Rep. Gunderson (R-WI), one prohibiting FDA from approving the hormone until Congress is provided an analysis of its effect on the environment, milk production and price supports, and another requiring USDA to report to Congress on the impact of BGh on milk production and price supports; and

- statements or resolutions from a number of farm and dairy groups, including the National Grange, Vermont's Cabot Co-op Creamery Co., the Empire State Grange of New York, and the National Milk Producers Federation, calling for a postponement or flat out prohibitions on using BGh-produced milk until all questions are put to rest.

In addition, a number of social, ethical, and economic questions have emerged with the proposed use of bGH. For example, will the use of BGh in dairy cows facilitate their "burn out"? Does BGh have any effect on disease susceptability or fertility in dairy cows?[13] Will some agricultural regions benefit at the expense of others with the widespread application of livestock biotechnologies? Will consumers react differently to animal products derived from livestock treated with a genetically-engineered hormone?

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13 One of the companies that wants to sell Bgh, American Cyanamid, began a study of the hormone's effects on the animals at a University of Pennsylvania veterinary farm near Kennett Square, PA. That study involved 40 cows, and the resulting yeilds were as good as those found at Cornell --20 to35% increases. But in the Cyanamid study, 8 of the cows were slaughtered when it was discovered that they were unable to conceive. These 8 cows received the very highest dose of Bgh --50 milligrams-- now understood to be an excessive amount. Scientists at the U. of Pa. vet school warn that it would be dagerous to conclude that Bgh caused the cow's sterility, but concede that more study is needed to determine if long-term accummulation of Bgh may be harmful to the animals. Others believe that Bgh will increase physiological stress in the animal, making it susceptible to a range of disease and metabolic disorders.

Some organizations, such as the Rural Advancement Fund International, based in Pittsboro, NC, have expressed concern about bGH's contribution to the narrowing of the genetic base:

> Virtually all tests of bGH have been conducted on Hostein dairy cows, the most efficient and productive milk breed. Holsteins now represent well over 90% of the U.S. dairy cattle population and undoubtedly be the breed selected for commercial application of bGH and other technologies designed to enhance milk production. Adoption of bGH (in combinantion with a reduction in the number of diary cattle) will thus facilkitate a narrowing of the genetic base of dairy cattle in the U.S. and abroad.
>
> Genetic diversity is vital to the future of modern livestock production. Minor breeds, for example, carry invaluable disease and pest resistance and many other qualities (e.g., hardiness, high butterfat content, better roughage conversion) which Holsteins may not possess... (Rural Advancement Fund International, 1986)

Alternatives to bGH

While bGH is being viewed as perhaps the most powerful production aid to come to the dairy industry in recent years, there may be other research options for dairy productivity that have not been pursued or have not been considered in an integrated fashion.

For example, USDA's Users Advisory Board noted the following in its 1988 budget report to the President and Congress:

Researchers in all agricultural areas should be asking the kinds of questions that could lead to the development of less expensive technology. In the area of milk production, for example:

- Can monoclonal antibodies identify those cows whose circulating bST level would permit them to produce more milk if switched to a higher protein feed?

- If higher milk production can be achieved by higer levels of growth hormone, could DNA probes be developed to help select those embryos which contain the highest levels of the hormone?

The Public & University Investment in bGH

Approximately $1.2 million in federal funds have been used to support basic and applied research on bGH. And $2.5 million in private funds have been used to support research at publicly-funded universities and research centers in the land grant system. (Nat'l Agricultural Library).

Among the universities involved in the research and testing of bovine growth hormone, is Cornell University. Dave Call, the Dean of Cornell's Agriculture College, outlined the history of bGH development, and Cornell's involvement, at a 1987 Brookings Institution conference in Washington.

In his talk, Call explained that the research on bGH dates to 1939, when the first Russian study on pituiitary extracts was published. In 1940, during the war, researchers in the U.K. used pitutitary extracts to get greater milk yields in cows. In 1950,

bovine somatorpin was first purified. By 1973, Monsanto had produced an even more purified version of Bst and saw yields increase further in experimental animals. By 1978, at Cornell, two scientists then working on the basic biology of animal productivity, Dale Bauman, an animal nutritionist and Bruce Kerry, an animal physiologist, teamed up to focus on the regulation of nutrient use in ruminant animals, and began work on 3 protein hormones, one of which was Bst.

In 1980, the Cornell scientists convinced Upjohn to produce quantities of natural bGH for experimentation purposes. Then in 1981, Monsanto and Genentech annonced they had synthesized bGH by recombinant methods. In 1985, a paper the Cornell team published in conjunction with Monsanto "caught everybody's attention",according to Call, despite the fact that there were some 60 papers published on the subject.

In regard to the financing of the Bgh project at Cornell, Dean Call says there wasn't "any one piece of funding" that accounts for it all. Hatch funds started the process, he says. But there was also money from Cornell's Biotechnology Institute, from USDA competitive grants, and some $500,000 from companies such as Monsanto, Merck, Upjohn, American Cyanamid, Genentech and Agway over a three-to four year period. (Call, 1987)

Today, Cornell has research contracts with American Cyanamid, Monsanto and others for work on bovine and other growth

hormones. "But the money has to fit", explains Call; it has to fit Cornell's long-term goals of productivty, and all the work must be publishable by the investigators. Call says that the university has "turned down deals with corporations that wanted the patent".

With regard to where bGH fits in within the university's research agenda, Call says that increasing dairy efficiency and productivity have always been a priority at Cornell, "ever since Ezra Cornell and his dairy cows"... Cornell has always had a long-term commitment to animal productivity, he says.

In terms of prioritizing agricultural research at Cornell, Call says that they haven't thought about priorities that much. Research is something that is re-oriented very gradually, he says, "when we hire new people". This inovlves making a 30-to-40 year commitment to research, through tenure. Researchers are the driving force behind research, he says.

With regard to the economic impact of bGH, Call says that "early on, we knew this would have economic impact". And as early as Spring of 1983, the university allocated $40,000 for 3 years to look at the economic impact of Bgh, and the review involved 6 faculty members. "The point is", Call explained at Brookings, "we tried to be up-front about this. At an October 1984 conference, we made the first announcement at Cornell on the economic impacts of Bgh".

Another university involved in the testing and development of bGH has been the University of Wisconsin. The U.S. Dairy Forage Research Center at Sauk City, WI is also invlolved, where two 32-cow herds--one a control group, and the other the test herd--are being used.

Larry Satter, acting director of Wisconsin center, believes the university should not be faulted for its research on bGH:

> We are doing what's needed so farmers can issue a safe, reliable, economical food supply. We have a special interest in producers. That's who we work with, but we also have to consider the publlic at large. It would be a disservice to the public at large if our research was limited to improving the profitability to jsut the producer, and the consumer was not considered. Withour consumers, there would not be very many producers. These are very sensitive issues.
>
> Our research is aimed at trying to lower the cost of production so dairymen can have more room to work in--so they can maintain profitablity and sell product at a reasonable price. Technology makes it possible to have an econommic product and profit for producers. (Fyksen)

One group that has recently raised questions about bGH is USDA User's Advisory Board:

> Bovine somatotropin (bST) provides an example of what appears at this stage in its development to be an expensive technology for an inexpensive commodity--milk. The research and the regulatory process are expensive. A long-term private sector pl;an plus a large capital investment by the manufacturer are required in oreder to develop and implement the technology...

> If public policy demands more and more production per animal or land unit, there will be continued innovation aimed towards higher productivity at higher levels of input costs. Bovine somatotropin is an excellent example of an innovation driven by a public policy which emphasizes per-animal productivity. If the public policy base is changed to emphasize per-farm productivity levels based on current wold supply-demand ratios, however, an entirely different menu of technologies will appear.
>
> Expensive technologies such as bovine somatotropin (in its present stage of development) will remain attractive to manufacturers only if public policy rewards the most productive farmers and maintains support prices near their present levels...

One of the conclusions in the UAB's anaylsis of the effect of bGH was, in effect, that it would primarily benefit the largest, most skilled, "supercow" operations--those producting 20,000 lbs of milk per cow/per year. According to the UAB, these operations would see "meaningful profits", even at price supports at the $10.00 level, which would be a 10 % reduction of current levels. The remaining farmers would be profitable only if price supports stayed at current levels, and in some cases, rose above current levels.

In other words, this "efficiency" achieved by bGH--if allowed to work its will on the diary sector--would allow production to increase, consumer prices to drop, and dairy price supports to decline--a very attractive political situation for a Congress pressed on spending matters and incresingly dominated by urban interests. Yet also, the publicly-subsidized research and

testing behind bGH that leads to "a more efficient agriculture", will also bring about the further consolidation of the dairy industry, reducing farm numbers (some have siad by as much as one half in 10 years), also impacting small-town rural economies. But does this research outcome meet the tests of: 1) the "improvement of the rural home and rural life" as stated in the Hatch Act of 1877 ? or 2) the promotion of "a sound and prosperous agriculture and rural life as indispensable to the maintenance of maximum employment...national prosperity and security" as stated in the 1955 amendments to that Act ?

CASE STUDY #2: DISEASE & INSECT RESISTANCE RESEARCH

Disease & Insest Resistance in Crops. Today, in the United States, there are approximately 150 crop varieties resistant to one or more kinds of disease, 150 varieties resistant to nematodes, and over 100 varieties resistant to some 25 types of insect pests. Impressive as this may sound, however, there are no crop varieties resistant to many diseases and insect pests, some of them quite damaging. In the Midwestern Corn Belt, for example, there are at least 30 insect pests and 50 disease pathogens that can attack corn. So far, corn varieties have been developed that resist about 22 of the most damaging corn diseases. The record for developing new insect-resistant corn

varieites is not as good.

One pest, the western corn rootworm, has been expanding its range by 140 miles a year in an ever-enlarging circle that began in southern Nebraska in 1960. It is now found in 18 stattes. In addition, some chemical insecticides used to fight this pest are now showing up in midwestern growundwater supplies. As of 1984, no rootworm-resistant corn varieties were available. One major obstacle is that no corn germplasm with resistance to this pest has been identified.

In the southeastern United States, chemical pesticides -- not resistant plant varieties -- have been the chief means of controlling soybean pests. In Alabama, for example, the root-knot nematode and the soybean cyst nematode are particulalry vexing problems. Both has been almost entirely controlled by two nematicides --ethylene dibromide (EDB) abd dibromochloropropane (DBCP) --until EPA banned them for public health reasons. That prohibition revealed just how dependent soybean gwoers were on these pesticides, as well as how little plant breeding had been undertaken in the a region to develop nematode-resistant soybean varieties. Today, in some breeding programs, some resistance breeeding is being conducted.

The new knowledge coming from the workbenches of molecular biology should make it possible to avoid some of the limitations of conventional plant breeding for resistance. It should also

speed up the process of germplasm screening and evaluation for resistance traits. And with the ability to transfer genes from one species or genus to another, genetic engineers need no longer confine their search for resistance genes to compatible species. Some biotechnologists even talk boldly of making crops "immune" to disase and insects. Monsanto's vice president for research and development, Howard Schneiderman, has predicted that some genetically engineered crops resistant to insects and other pests will be on the market by the 1990s. The result, he adds will lead to decrease dependence on pesticides. "We will have shifted the central thrust of plant protection in some key areas from treatment to prevention". (Schneiderman, 1984)

This approach in dealing with pests, however, might not come without difficulty and side effects. In the development of insect and disease resistant varieites using conventional techniques, plant breeders have generally employed a one-gene/one-pathogen type of resistance, sometimes called "gene-for-gene" breeding -- a practice that may be followed in genetic engineering as well. Crop varieites with single-gene resistance are almost completely resistant to the predominant strain of pest --until an adaptation occurs. Just as a pest can become immune to a pesticide, so can it overcome the resistance produced by a single plant gene. Single-gene resistance more or less beckons adaptation by the pest and its mutation into new strains, rendering the crop variety, if widely planted,

susceptible to devastation or epidemics.

There is some evidence suggesting that the use of single-gene breeding may be contributing to a corresponding increase in the frequency of virulence genes in the pathogens that attack certain crops. This has been reported in Australia, for example, in breeding wheat for resistance to stem rust; barley for resistance to powdery mildew; tomato for resistance to leaf mold; and lettuce for resistance to downy mildew. Many pathogenic organisms have the ability to trransfer genes among themselves asexually, increasing the rate at which they can overcome single-gene defenses in crop varieites. This is one reason why some new crop varieites last as little as five years before they are overtaken by a new strain of pathogen.

"Intensive modern agricultural methods accelerate the evolution of new pest types, requiring plant geneticists to more rapidly breed genes into commercial cultivars form resistant relatives", says Calgene, a California biotechnology company,in one of its recent brochures. The company says that biotechnlogy "will speed this transfer process to keep pace with the pathogens, expand the gene pool to unrealted organisms, and even create synthetic resistance genes in the test tube". But if genetic engineering continues to employ gene-for-gene plant breeding, might it not simply speed up and extend the practices of the past, thereby hastening the adaptation of existing strains, giving rise to new insect and disease problems?

On the other hand, biotechnology might help plant breeders to impart a broader, multiple-gene type of disease and insect resistance to agricultural crops. But that will be more difficult to accomplish in the short run. Scientists are just beginning to learn of the interaction of pest and plant genes, and more basic knowledge in this area is needed. And, so far, only single-gene traits have been successfully transfered. Moving multiple-gene traits successfully and achieving coordinated expression --without affecting other plant functions -- is a considerable challenge.

Disease and Insect Resistance in Livestock. The goal of achieving disease and insect reistance in livestock agriculture could also be elevated to higher priority within the USDA-led agricultural research system. In its January 1983 Agricultural Research Service Program Plan, this goal is mentioned under Objective # 3, as one approach: to "improve genetic resistance of animals to diseases and internal and external parasites". In this report, ARS states that "long-term research is needed on genetic manipulation to produce animals that are resistant to diseases and parasites". The reports adds, "if we could identify the genes and thier products that makes certain animals suceptible or resistant to parasites and diseases, resistance might be bred into livestock". Yet how much money and scientific manpower is being devoted to this area of research?

Although there is some work on disease and insect resistance now going on in both the public and private sectors with the help of biotechnology, a much more concerted and thoughtful effort --particularly with more durable resistances in mind--could be launched by the public sector system.

CASE STUDY #3: GENETIC ENGINEERING OF MICROBES

Researchers in the public and private sector are working on ways to genetically engineer bacteria, fungi, and other microorganisms for use in agriculture as pest control agents and to assist plants in the use and uptake of nutrients.

The bacterium Bacillus thuringiensis, known as Bt, kills the insect larvae of lepidopterous insects (moth and butterfuly) with toxic crystals formed in its spores, when those insects inject the bacterium. Some commercial intersts, such as the Monsanto Company, have proposed genetically engineering Bt's toxin gene into another bacterium, Pseudomonas flourescens, for use in fighting black cutworms in Midwest corn soil.

One of the goals of biotechnologists now developing genetically altered microbes for use in agriculture is to make them behave like broad spectrum chemical pesticides--i.e., to make them kill more than one specific pest and to make them more

persistant in the environment. Ecogen, a biotechnology company fomed specifically to genetically engineering microbes for pest control, is one of the companies looking into this possibility. Ecogen's Bruce Carlton has outlined some of the possiblities in this area:

> "Cloning of two or more genes for distint pesticide activity in the same host cell could generate a mutipurpose pesticide, having activities against two or more very different targets (e.g., two different insects, an insect and a weed, and an insect and a fungal disease). The relative ease with which such different gene combianations can be potentially constructed by recombianant DNA technology makes the possibilities virtually unlimited". (Carlton, 1984)

But by using biotechnology to build "multiple-warhead" microbes that kill more than one species of pest, or those that last longer in the environment, we may be creating bigger ecological and/or public health problems than those we hope to replace. There has been little scientific study or data collection on how existing non-engineered organisms behave in nature, let alone any solid understanding of how genetically altered one might behave.

Will the toxins inserted genetically engineered into microbial pesticides kill beneficial microbes or insects? Will they persist in the environment?

Our ability to make predictions about what might happen with genetically engineered organisms in the environment will

have to build on the what is known about the ecology of existing organsims. However, we haven't systematically collected much ecological information on existing organisms.

Many ecologists agree that there is little scientific information on which to base predictions about the behavior of engineered organisms. (Alexander, 1985). Little is known about the dynamics of how organisms establish themselves, or why some species multiply in nature and others do not, or what attributes make some organims good at dissemination and others poor.

Some scientists estimate that as many as 80 percent of our soil microbes have yet to be cultured, and perhaps as many as 90 percent don't have names. Of those that are named, we don't know much about their relationship with other microbes.

There are a number of key questions that need to be asked about "deliberate release" experiments in order to determine potential risks and side effects: 1) Will the organisms survive? 2) Will they multiply? 3) Will they transfer their inserted genetic changes to other organisms? 4) Will they be dispersed or transported to new or unintended sites? 5) Will they have a deleterious environmental effect? 6) Will they pose public health risks? and 7) How will they be contained or destroyed should they pose a health or enviromental threat?

In February 1985, the Cornell University Ecosystems Research Center issued one of the first comprehensive overviews of what

was possible and what was lacking in the way of assessing the enviromental risks of new biotechnology products. The findings of that report are fairly remarkable, and underscore how little we know about microorganisms --how they survive, how they are dispersed in the environment, why some grow rapidly, and why others do not.

But the clincher in the Cornell study is what it said about the ability to make predicitions about the behavior of organisms in the environment: "Methods for predicting the likelihoood of survival and proliferation of a given organism in the environment are crude... Methods are available for assessing some potential effects, but there are many deficiencies in current knowledge and theory. Generally, we lack any true data base against which to compare test results or predict environmental consequences."

The U.S. Environmental Protection Agency's Scientific Advisory Board released a January 1986 report that echoed some of the same concerns about data deficiencies and the present state of our ecological assessment capabilities.(SAB-EPA, 1986). In addition, a growing list of ecologists, entomologists, population biologists, and evolutionary biologists continue to raise new concerns independently of offical government bodies. (Sharples, 1986)

Given the risks and the uncertainties with the use of gentically engineered microbes in agriculture, does it make sense

to be heaviliy investing public and private research dollars in this use of biotechnology if when there are other options that accomplish the same result with less risk?

CASE STUDY #4: HERBICIDE RESISTANCE IN PLANTS

During the 1970s, some plant breeders began to think abuot ways to protect seed and new crop strains from the harsher side of herbicides. One of the first products marketed to help crops tolerate soils laden with, or to be treated by, toxic herbicides was "herbicide safened" seed. Ciba-Geigy, the Swiss pharmaceutical company, introduced one such product in 1979.

Ciba-Geigy and its subsidiary, Funk Seeds International, acquired in 1974, called their product an herbicide antidote, and named it Concep. Concep is a chemical coating applied to sorghum seeds to protect them from the damaging effects of herbicides such as Dual, Milocep and Bicep, all of which Ciba-Geigy sells. This seed coating -- which blocks the toxic action of the sorghum herbicides on the seed -- is a trademarked process called Herbishield, and can only be applied by saed companies. "By planting Herbishield seed," says the Funk Seed Company in an advertisement for farmers, "you will be able to use Bicep, Milocep, or Dual herbicides for more effective control of grassy weeds."

But some herbicides have another problem: they linger too long in the soil, damaging crops that may follow in rotation. For example, some triazine herbicides, including the popular atrazine, have been selected to work with one or a few crops, killing were but not the crop. Corn can tolerate atrazine because it contains certain enzymes which detoxify the chemical inside the plant. Thus, corn is naturally resistant to artizine's lethal effects. But his is not the case with soybean, a crop often used in rotation with corn. And that can be a problem when atrazine is still present in the soil. A farmer using atrazine on corn, and then following that corn crop with soybean crop, is likely to have atrazine-damaged soybeans and reduce yield because of atrazine soil residues. Other crops, such as alfalfa and small grains, are also sensitive to atrazine residues. Some herbicides may leave crop-damaging residues for as long as four years after they are first applied.

One solution to this problem has become clear with gene-splicing research: find the specific genes that enable a given crop to resist the ill effects of certain herbicides and move those genes into the sensitive crop.[14]

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14 During the late 1970's some scientists began to investigate the genetic and biochemical mechanisms in weeds that made them resistant to certain herbicides. One plant biochemist, Dr. Charles Arntzen, leading a team of investigators at Michigan State University, spent three years pursuing protein chemistry techniques to unearth the mechanisms of atrazine resistance in weeds. Meanwhile, another group of investigator at the Harvard University laboratory of Lawrence Bogorad, was studying gene expression in plant chloroplasts. After collaboration, the two groups discovered that a single nucleotide change in one gene found in the chloloroplast was the basis for the weed's resistance to atrazine. Presenting these results to the Miami

In 1982, American Cyanamid, the nation's sixth largest chemical company, struck a deal with Molecular Genetics, a biotechnology company, to develop new lines of hybrid corn resistant to a new class of experimental herbicides called imidazolinones. "The new lines of corn," reported Chemical Week in 1982, "are expected to increase the market for broad-spectrum herbicides, which otherwise have a limited potential when used with current hybrids of corn."

In November 1982, Calgene, a California based biotechnology company, announced that it had cloned a gene for resistance to the world's most widely used herbicide Monsanto's Roundup, chemically named glyphosate. Two years later, Calgene had contacts to develop herbicide-resistant crops with at least three major corporations: Kemira Oy, Finland's largest chemical company; Nestle, the world's largest food company; and Phone-Poulenc, a major French agrichemical company.

Today, more than 30 corporations and biotechnology companies and biotechnology companies are involved in herbicide resistance research, either through funding agreements or direct in-house R&D. (See Table). In other words, these researchers are enlisting the powers of bioengineering to enhance and broaden the use of herbicides in agriculture: that is, they are planning

Winter Symposium in January 1983, Arntez suggested that such resistance could be genetically engineered into important crop plants, such as the soybean. By this time, chemical and pharmaceutical companies had already begun their own programs of herbicide-resistance research.

to give crops that may be damaged or killed by herbicides the genes that will make them tolerant of, or resistant to, the chemical's damaging side effects. This comes at a time when EPA has banned some herbicides, listed several others for groundwater monitoring and/or special toxicology reviews. Laboratory animal studies have shown some of these chemicals to be possible carcinogens. At least 15 herbicides -- many of which were once billed as rapid breakdown and non-persistant products -- have recently been detected in surface and groundwater across the country.

Table 10.

HERBICIDE RESISTANCE RESEARCH-- PRIVATE SECTOR

Company	Research Description
Allelix	Herbicide resistant oilseeds
Advanced Genetic Sciences	AGS scientists have isolated tobacco mutants resistant to various herbicides by screening protoplast-derived colonies, and will be extending this project to other crops; also attempting to introduce genes into crops that would make them resistant to particular herbicides (1983 prospectus)
American Cyanamid	Seeking resistance in hybrid corn to new class of herbicides known as the imidazolinones, including Scepter; also working in other field crops
Bayer-Mobay	Work on herbicide activity and site of action; particular interest in improvement of crop tolerance via natural or

	synthetic means
Biotechnica Int'l	Development of detoxification genes for major proprietary & non-proprietary herbicides; working to develop a vegetable variety that will withstand "less selective" herbicides (1983 prospectus)
Calgene	Variety of basic research on herbicides' mode of action and molecular & cellular techniques useful for isolating, cloning, and transferring critical genes; collabortative efforts with major agrichemical and seed companies involving proprietary products
Campbell	
Ciba-Geigy	Development of seed coatings to protect germinating seedlings from proprietary chemicals; seeking tolerance to atrazine in tobacco (for use in soybean, eventually); field tested in tobacco summer '86
Chevron	Work underway with paraquat & other proprietary chemicals, including Selectone
DNA Plant Technology	
Diamond Shamrock	Resistance to 2,4-D in soybeans, small grains
Dow Chemical	Variety of basic & applied research underway with proprietary chemicals, including Verdict
Du Pont	Development of resistance in major crops to new sulfonylureas & other proprietary compounds; wide range of basic research
Eli Lilly	in-house program seeking resistance to Treflan (trifluralin), presumably in corn, sorghum, oats & others

FMC	Resistance to new proprietary product, FMC 57020
Heinz	
Hoechst	Resistance to the non-selective herbicide glufosinate
ICI	Range of basic work on plant molecular biology; work underway with proprietary chemicals, including Reflex
Int'l Paper	Seeking resistance to certain herbicides for Douglas Fir
Kemira Oy	1983 research contract with Calgene to develop herbicide resistant turnip rape for use in Europe
Lubrizol	Focus on resistance in oil-seed crops
Molecular Genetics	
Monsanto	Wide range of basic & applied reseaerch targeted at Round-up (glyphosate) & other proprietary chemicals
Nestle	Nestec has 1984 research program with Calgene to develop herbicide tolerant soybeans
Pfizer	Variety of crops & chemicals with Dekalb-Pfizer; joint venture with Calgene
PhytoDynamics	seeking resistance in corn to Treflan, Round-up, and Prowl (penoxalin)

Phytogen	working with tissue culture & gene splicing to produce crops resistant to Roundup; research & marketing agreement with Calgene for glyphosate-tolerant cotton
PPG Industries	Resistance to promising proprietary herbicides, including Cobra; joint venture with Calgene
Rhone-Poulenc	Seeking resistance in sunflowers to proprietary chemical bromoxynil; other basic work underway; 1984 contract with Calgene
Rohm & Haas	Seeking resistance to proprietary chemicals
Shell	Studying mechanisms of resistance to new proprietary herbicides, including Cinch (cinmethylin)
Stauffer	Seeking resistance to proprietary herbicides in corn, sorghum & sunflowers

Sources: Compiled by the Environmental Policy Institute, Wash. DC, from: Charles M. Benbrook and Phyllis B. Moses, "Herbicide Resistance: Environmental and Economic Issues", Paper for BioExpo 86 Biotechnology Conference; and Department of Rural Sociology, University of Wisconsin, "Companies and Institutions Working on Herbicide Resistance in Plants", As You Sow..., No. 2, February 1986, p.2

The first genetically-engineered herbicide-resistant crop strains are expected to reach the market by 1988. Ciba Geigy has already conducted the first USDA-approved field test of a herbicide-resistant crop strain, and others may be tested this year and next. DuPont, Calgene, and Monsanto are not far behind.

In addition to this commercial activity, public funds from the U.S. Department of Energy, the National Science Foundation and the U.S. Department of Agriculture have been used to support herbicide resistance research at a number of universities and agricultural experiment stations including Auburn University, the University of California, Davis, the University of Chicago, Harvard, Louisiana State University, Michigan State University, Rutgers, and the University of Tennessee. In other instances, such as the work on atrazine resistance, university research has been supported or conducted in collaboration with private companies such as Ciba-Geigy and Shell Agricultural Chemicals. And while some of this research in the iniversities had been aimed at getting basic knowledge about plant molecular biology, much of it is now justified on the making of herbicide resistant crops and forest trees.

Industry officials and scientists say the making of herbicide-resistant crops, with the help of biotechnology, will only help herbicides to do their job more efficiently. Herbicide-resistant crops, they say, will allow better targeted usage, as well as be safer for public health and the environment. And if market anylysts are to be believed, herbicide resistant crops will help the sale of herbicides.[15]

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15 In July 1982, Chemical Week wrote of a "slow but steady push," among herbicide makers toward the "genetic manipulation of corn, soybeans, and other crops to make them more resistant to herbicides." "The theory is," explained the magazine, "that farmers would then be willing to use even more of the weed killers, safe in the knowledge that their crop won't be damaged."

"Use of genetic engineering to develop herbicide-resistant

Table 11.

PUBLIC SECTOR RESEARCH ON HERBICIDE RESISTANCE IN PLANTS

University/Agency	Research Description
University of Alabama	working to make crops atrazine resistant
Univ. of California -Davis	working to make sunflower resistant to sulfometuron
Univ. of Chicago	researching molecular basis in plants for resistance to triazines
Cornell University	working to make corn resistant to the triazines
Harvard University	working on atrazine resistance in soybeans
Michigan State University	working on atrazine resistance in soybeans
Rutgers University	working to make certain crops resistant to the triazine herbicides
USDA-ARS	working to make soybeans resistant to metribuzin
U.S. Forest Service	working to make Poplar trees resistant to glyphosate & Jack Pine resistant to the herbicide hexazinone

Source: Compiled by Environmental Policy Institute, Wash., DC from Univ. of Wisconsin, Dept. of Rural Sociology, As You Sow..., February 1986

While some of the new low-dose herbicides may indeed be safer than those of the past, this does not mean they are toxic-free or incapable of being misused. American Cyanamid's new family of herbicides, the imidzaolinones, for example, have low mammalian toxicity; they are not toxic-free. Other herbicides, such as DuPont's Glean and Monsanto's Roundup are claimed to be among the safest chemical compounds developed by industry so far, but not much is known about the long-term effects of herbicides in the environment or how they break down. Moreover, recent discoveries of herbicides such as alachlor, atrazine, and paraquat showing up in groundwater in states such as Iowa, Nebraska, and Maryland have raised new questions about herbicide safety. In addition, many existing herbicides, thought less toxic than their predecessors, have not been adequately tested

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crop plants," predicted Genetic Technology News (GTN) in April 1984, "is likely to bring a complete restructuring of the current $2.4 billion-per-year U.S. herbicide market. And GTN added that herbicide-resistant crops "may open up a few entirely new applications for herbicides."

The L. William Teweles Company, a seed and biotechnology consulting firm, reports that some chemical companies are developing crops resistant to their herbicides "in the hope of selling the seed and chemical as a pair." Other companies are seeking herbicide resistance, according to Teweles, "as a way of gaining market share lost after a well-known herbicide has declined in price and popularity [with] the old herbicide [being] sold in combination with a new seed resistant to it." Such a marriage between herbicides and seed, says Teweles' James Kent, "is a natural." Kent views herbicides-resistant crops as creating "a complementary demand for both chemical and seed." George Kidd, also with the Wm. Teweles Co., states that with the development of atrazine-resistant soybeans, for example, atrazine use by farmers each year would double or triple over what it is now, increasing sales by about $120 million annually. (Genetic Technology News, 1984)

for their possible mutagenic, carcinogenic and teratogenic effects.

Unless all herbicide alternatives are pursued with equal vigor--either by commercial and/or the public sector, using conventional or biotechnological techniques--the primary conclusion that begs to be drawn from this line of herbicide resistance engineering, is that this technoogy will be used to extend the pesticdie era rather than end it.

Alternative Weed Control Strategies

As chemical herbicide development continues -- now intensified by the use of biotechnology to make crops genetically tolerant to high herbicide environments -- non chemical, alternative approaches to weed control might run the risk of being completely overshadowed by the "sexier" biotechnology research trends. Yet alternative, nonchemical weed control strategies -- and even a few products-- are available, and other research shows promise.

In 1981, Abbott Laboratories of Chicago registered a fungus with EPA named Phytophthora palmivora. This particular fungus is a naturally-occurring organism, discovered in Florida soil, that induces a disease in the citrus strangler vine, or milkweed vine, that plagues citrus groves in Florida. Abbott sells this myco-herbicide, as it is called, under the trade-name Devine. It

is a highly effective, highly specific (attacking only milkweed vine) herbicide, and does not harm citrus trees or fruit. In fact, this fungal herbicide is so effective that retreatment in some Florida groves may not be necessary for several years.

The Upjohn Company also produces a fungal herbicide that attacks the weed, Northern Join vetch, which is a problem in rice and soybean fields. Upjohn's product, tradenamed Collego, was registered with EPA in 1982.

There are also some interesting possibilities and future potential in the science of allelopathic chemicals -- those chemicals emitted naturally from certain crops and weeds (or microorganisms) that might be used in place of chemical herbicides. Some scientists in the public sector, for example, see a day when farmers might use a cover crop of rye or clover as they now use chemical herbicides.

Plant pathologist George Waller of the Oklahoma State University in Stillwater notes that a cover crop of rye left on the soil as residue and not cultivated, will leave enough allelopathic toxin in the soil to inhibit weed growth, while allowing crops that are seeded below that surface to grow normally without any side effects. Similarly, North Carolina State University weed scientist A.D. Worsham reports that when full-season soybean and sunflower were planted "no-till" into fields of killed green rye, the growth of such pesty weeds

as lambsquarter, pigweed, and ragweed were reduced 92 to 99% compared to cultivated plots.

Alan R. Putnam at the Pesticide Research Center at Michigan State, and William B. Duke of Cornell's Agronomy department, noted the allelopathic properties of cucumber in suppressing weed growth as early as 1974, and suggested the possibility of moving such traits into commercial crop varieties through conventional plant breeding. Today, gene splicing and biotechnology cold, no doubt, enhance the range of possibilities for incorporation such allelopathic traits into commercial crop varieties.

Other approaches to nonchemical weed control could proceed without the help of biotechnology. The successful application of biocontrol using plant-eating insects has been repeatedly demostrated (see "Biological Control of Weeds in the United States," JPR 5(3):18-20). Cochineal insects imported from India in 1856 ate prickly pear cactus in Ceylon. In the 1950s and 1960s, a runaway ornamental, lantana, was partially controlled in Hawaii with insects from South Central America.

Use of plant-eating insects to control weeds is currently being largely ignored in the U.S., however, in the rush to employ biotechnology and herbicides. Nevertheless, says the U.S. Department of Agriculture's Lloyd Andres, "All weeds have natural enemies somewhere in the world."

Calls For a Change in Direction

With the farm crisis of the last few years, world commodity surplusses, and the growing side-effects of modern productin agriculture, there have been increasing number of scientists and a few agribusiness leaders questioning modern agricultural production techniques and status quo agricultural research.

For example, some individuals have begun to raise concerns about high-yield agricultural systems. William L. Brown, former CEO and Chairman of Pioneer Hi-Bred Insternational and now head of the National Academy of Sciences Board on Agriculture is one of those asking questions. "As we offer the farmers increasingly sophisticated and costly technological packages", he told an audience in 1984, "we inadvertently exacerbate two related sources of instability in agriculutre. High-yield production systems are often more volatile in terms of harvested production, and more erratic in terms of profit for the farmer". (Brown, 1984).

USDA'a Users Advisory Board has also noted the high cost of inputs; costs that are incresingly difficult to "cover" with yield or higher price supports:

> The variable input costs associated with planting corn, for example, have increased by $55 per acre since 1976. At today's target prices, yield increases of 18 bushels per acre would be necessary just to cover the rise in input costs. The same increase--about 18 bushels--would be necessary to cover the rise in input costs in wheat. Increases in productivity cannot ensure increases in profitability. (UAB, 1987)

One of the UAB's recommendations in its report is that research in the public sector should be encouraged to make profitability--not simply productivity--its objective. And the UAB report also goes to some lengths to explain how agricultural technologies can sometimes have unintended consequences:

> Technology can have different and unobvious impacts on various categories of operators. The economic benefit of a technology depends on the input costs to the farmer and how any resulting increase in production volume will affect the market price of the commodity in a glutted market.
>
> An inexpensive technology can be a useful strategy for increasing profitability and reducing the need for subsidies. Because the future will see lower commodity prices, farmers will need a new menu of technologies that recognize new goals: profitability, environmental protection, rural development, and world competitiveness.
>
> On the other hand, if a relatively high-cost technology significantly increases production in a glutted market, the market price can fall sufficiently to erase any increase in profitability which the farmer may temporarily receive from adopting the technology. In a subsidized market, the American taxpayer pays a share of the bill for the new technology. (UAB, 1987).

In terms of the agricultural research agenda, the UAB sees a different era emerging; one that requires thorough questioning and careful economic impact analysis <u>before</u> advances are automatically put into use:

> Many of today's agricultural problems are different from those of the last 100 years. The problems faced by the scientists in the Agricultural Research Service and the Cooperative State Research Service for the most of this century have been related to finding ways to increase productivity when world demand outstripped supply. Now that most developed nations are self-sufficient

in food production, the United States faces high supplies of most major commodities...

...The Users Advisory Board strongly supports research into promising new areas of technology. It is vital for researchers to be able to explore freely, pursuing whatever avenues their work opens up to them. It must be recognized, however,that while many research results will be remarkable and may reveal previously unimagined possibilities, they should not be automatically presumed worthy of large-scale development and implementation.

The oversupply situation which exists for most U.S. commodities, makes it essential to concentrate on technologies which have the potential to improve the profitability of farming. All large programs in the public sector should be subjected to economic review as early as possible in the development scheme. A sensitivity-cost analysis shoudl be included, as well as studies diesigned to determine the impact of the technology on various scale and skill segments of farmers, the subsidy programs, and world competitiveness. (UAB, 1987)

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Conclusions & Recommendations

In many ways, agricultural biotechnology presents the nation with a number of opportunities and choices--research choices, institutional choices, and economic choices. In the years ahead, where agricultural research is pursued--that is, the institutional "container", with its philosophy and orientation--will be just as important as what is pursued.

There is now a tendency in Washington, abetted to some degree by the states--to tilt research dollars away from the

"old" USDA land grant/experiment station complex, in favor of a "new" strategy that includes universities with a so-called "critical mass" of interdisciplinary science and/or specifically dedicated biotech centers. Much of this money and research appears to be moving in the direction of biotechnological product development in agriculture, rather than biological process understanding. The goal it seems, is to reduce biology to as many potential product opportunities as possible with new genetic and microbial products.

If the agricultural research agenda for biotechnology in the years ahead is increasingly tilted primarily toward such a many-product commercial agenda--with money, institutions, and scarce scientific talent all moving in that direction-- the agricultural system, too, will be cast and capitalized in that direction. The danger in this is that with such a research thrust, a high-cost/high-yield/high-risk system of agriculture will be continued that is capable of: 1) producing huge surpluses in the favored commodities which will periodically exacerbate farm programs and pricing stability; 2.) shrinking farm numbers dramatically; and 3) creating environmental side-effects and public health risks with new chemical and microbial products. But the public sector research system doesn't have to continue down that path.

Alternatively, public sector agricultural research institutions could be directed to prioritize research that

focuses more on a low-input/high-rate-of-farm-return system; one that stresses farmer profitability through low-cost production; biological processes and cultural management in the field; new crops diversification; and multigene, host-based disease and insect resistance for crops and livestock. Such a system, if introduced in a concerted and creative way, could result in less surplus, fewer environmental side-effects and public health risks, improved farm-sector stabilty, and greater rural employment opportunity.

Implementing such an agricultural research strategy, however, would take firm national and political resolve, reversing nearly 100 years of agricultural education, research and extension. Yet, such a transformation could occur if mobilized, organized, and funded through the existing land grant complex--a research and extension infrastructure that reaches into every agricultural region of the country. And precisely because the low-input approach will be stressing management based on local resources, biological appropriateness and diversification, rather than a broad-spectrum products approach that plays to big national and international markets, a local oriented research apparatus is exactly what's needed.

Public sector agricultural research programs need to be revitalized and re-credited in the public's eye. Yet using biotechnology to do that may backfire if the new technologies are used to pursue the same old goals, or to deliver to agribusiness

products that spawn the same or a worse set of side-effects. What is needed is a bold re-orientation of existing programs to capture benefits for farmers, consumers, the environment, and public health and safety in a way that has not yet been done.

One area that is ripe for such a concerted and coordinated research effort is in the general area of pest management and farm inputs--i.e., seeds, feed, pesticides, fertilizers, and livestock drugs. The goals here would be several, but predominantly, would include reducing the cost of farm input technologies currently used in U.S. agriculture, and reducing the public health risks associated with environmental, dietary, and worker exposure to synthetic chemicals and other agricultural supplements such as certain antibiotics and hormones used in livestock agriculture.

Farmers currently spend an estimated $18 billion annually for purchased feed, $7.4 billion for fertilizer, $4 billion for pesticides, and $4 billion for seed. That adds up to national cost-of-production bill of at least $33 billion, without including other related input costs. Any reduction in these costs would certainly improve farm income, and presumably, U.S. agricultural competitiveness. Moreover, the public health and environmental costs of using many of these farm inputs are also high, and could be decreased accordingly with a reduction in use.

In recent years, public concern has been growing over

the use of pesticides, livestock drugs, and other agricultural chemicals in agriculture. (see box, "The Growing Public Concern Over Pesticides")

With biotechnology, it may be conceivable to begin a research program that has as its goal phasing out pesticide use in agriculture. At the very least, it should be possible to drastically reduce the use of pesticides by "building in" disease and insect resistance into crops and livestock, and making that a major priority in USDA and the land grant system.

In fact, such a program could be targeted as a national goal--a goal no less important than putting a man on the moon, or NIH's war on cancer. Certainly, eliminating the source of one of our greatest public health threats, as well as a continuing source of groundwater pollution, and a primary source of farmer, and farmworker poisonings--would be a laudable national goal.

Such a program would elicit widespread public support and accomplish several things simultaneously. First, it would reduce public, farmer, and farmworker exposure to pesticides. Second, it would reduce the cost of production for farmers and thereby improve farm income and profitability. Third, it should improve consumer faith in the agricultural system and possibly reduce prices once all associated "pesticide costs" were reduced throughout the system. And fourth, it could provide a powerful basis for rejuvenating the land grant universities and

agricultural experiment stations.

Within the land grant and agricultural experiment complex, there is a need to re-instate the role of providing agricultural technology of broad public benefit. There is also a need to demonstrate consumer and environmental benefit in agricultural research initiatives. What better way to do this than through a major public sector research effort aimed at reducing public health risks and the farmer's cost of production through the development of non-chemical pest management strategies? The idea here is not to exclude the private sector, but for the public sector to "prime the pump", to take leadership in, and absorb the risks of, a major reorientation in agricultural production research that potentially could have wide public benefit.

However, with such a program, the definition of biotechnology and what is pursued in the name of non-chemical and/or biological alternatives will be absolutely crucial. What is needed is a biotechnology that embraces "common sense biology" and "common sense genetics", yet eschews the genetic engineering of organisms simply for the sake of making new products. What this means, however, is that we should use gene splicing and other biotechnology techniques, within reason, but that we should not disregard or overlook what we already know.

There is a lot of good biology already "on the shelf", so to speak. And there is a lot of good, innovative work going

on throughout the country by researchers at our land grant universities and agricultural experiment stations.[16] We have extensive information about soil tilth, plant breeding, crop rotations, intercropping, multilining, insect adaptability, agricultural diversification, and other fields--all of which has application today. We should not become so enamored of agricultural biotechnology that we go out of our way for a high-tech solution when a common-sense alternative is right in front of us.

In the context of using the land grant complex to launch a major new research initiative such as the one outlined above and in Table 12, Congressional approval and support would be absolutely essential. Moreover, there are other issues and other reforms that should also be brought forward in a general review of the land grant complex. In fact, a new Morrill Act/Hatch Act charter, re-written by Congress to reflect the new research priorities, and to reaffirm some of its original intentions, would be precisely the kind of public policy action that needs to be taken 100 years after the whole idea came to fruition.

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16 For example, Donald Barnes, a plant breeder at USDA's research center at the University of Minnesota, has developed a new variety of alfalfa called Nitro that produces good livestock fodder and puts high amounts of nitrogen back into the soil. When plowed back into the soil, Nitro puts 94 lbs. of nitrogen into the ground compared with 59 lbs. for the top standard variety. Nitro represents the kind of genetic improvement in agriculture that can save growers money on the input side of their operation, and thus, increase their profitability.

(for possible use as Box or sidebar)

THE GROWING PUBLIC CONCERN OVER PESTICIDES

Public Opinion. In a January 1984 consumer survey conducted by the Food Marketing Institute, 77 percent of those polled expressed concern over pesticide and herbicide residues in food, indicating the problem to be a "serious hazard".(Hammonds, 1984).

Public Opinion. A September 1986 Des Moines Register poll taken in Iowa shows that 58% of those surveyed believe farm chemicals are the biggest threat to water quality, and that 78% favor limits on farm chemicals.

Consumer Pressure. In May 1986, the Center for Science in the Public Interest began a national campaign called "Americans for Safe Food", with a 5-point plan of action that called for, among other things: laws that require disclosure of pesticides, drugs, and other chemicals used in the production of foods; a ban on pesticides and animal drugs known to pose a serious risk to consumers; and national standards for "organic", "natural", and "pesticide-free" foods.

Business Reaction. In July 1986, Safeway Stores, Inc., the nation's largest grocery chain, announced that it would stop buying apples treated with the chemical growth regulator Alar,, despite EPA's decision in January to allow its use while further studies are done. In addition, the state of Maine proposed a non-detectable standard for daminozide to be reached this year, and the state of Massachusetts has enacted regulation to reduce Alar in baby foods and heat-processed foods to a non-detectable level by 1988. (Wall Street Journal, 1986).

Business Reaction. In November 1986, the H.J. Heinz Co. announced that it was planning to restrict the purchase of crops used in the manufacture of baby foods that had been treated with certain pesticides. Heinz listed 12 chemicals: alachlor, aldicarb, captan, captafol, carbofuran, carbon tetrachloride, cyanazine, daminozide, dinocap, ehtylene oxide, linuron, and TPTH. Heinz told farmers that it would likely test crops for the absence of these chemicals -- all of which were then still legal, but under review by EPA as possible health hazards. (Meier, 1986).

Farmworker Health. In May 1986, United Farmworkers leader, Ceasar Chavez sent out a mass mailing appeal to Americans nationwide, announcing a new grape boycott aimed at eliminanting 5 pesticides that endanger farmworker health. In his appeal,

Chavez asked consumers not to buy fresh California table grapes until growers agree to ban the five most dangerous pesticides used in grape production -- captan, dinoseb, parathion, phosdrin, and methyl bromide. (Chavez, 1986).

Farmer & Farm Family Exposure. Last year, the U.S. Environmental Protection Agency warned women of childbearing age to avoid farmfields recently treated with the herbicide dinoseb because the chemical might cause birth defects. Another study, conducted by a team of medical scientists, found that Kansas farmers exposed to a widely-used corn and wheat herbicide for 20 days or more a year had a sixfold increase in a certain kind of lymph cancers compared to nonfarmers. And a third study from Wisconsin noted possible immune-system suppression due to aldicarb exposure.

(end box)

* * * * * * * * *

TABLE 12.

SOME POSSIBLE ELEMENTS OF A HIGH-PRIORITY
AGRICULTURAL BIOTECHNOLOGY RESEARCH PROGRAM
DESIGNED TO REDUCE SYNTHETIC CHEMICAL USE IN FARMING

1. Disease & Insect Resistance - Developing durable disease and insect resistance in all major and minor crops and livestock would become a top priority in all USDA, land grant, and agriculutral experiment station programs. "Building in" such resistances, using all genetic techniques available, would become the major thrust rather than fighting pests with chemicals. No new variety or livestock breed could be released unless it had some demonstrated resistance to at least one--and preferably more than one--disease pathogen or insect pest.

2. Biological Weed Management - Biological weed management strategies --using insects, crop rotations, alleleopathy, non-engineered weed pathogens, and other strategies--would be elevated to a much higher level of research and development than they are now.

3. New Fertility Strategies - Developing biological fertilization strategies that help to reduce, replace, and/or eliminante the use of synthetic fertilizers found jeapardizing public health or the environment would be the dominant thrust of this program. All strategies and/or combinations of strategies

would be sought, including microbial, crop breeding, and cultural strategies such as crop rotation.

4. Apomictic Hybrids & Open-Pollinated Varieties -
Hybrid crop varieties may be produced asexually through a process called apomixis, a clonal reproductive method known to occur in a number of basic grain species such as corn, wheat, rice, sorghum and alfalfa, and also in citrus fruits. Apomictic hybrids may be cheaper to research and could come to market quicker than conventional hybrids, but since they reproduce asexually, private sector has shown little interest and limited research exists in the public sector. Similalry, some research with open-pollinated lines of some grain species suggests that yields can approach hybrid levels in some cases.

5. Diversification Strategies - New crop and livestock research--including re-introduction of old and rare breeds--should be funded at a much higher level than is now apparent in the public sector. Land grants and ag experiment stations should be in vanguard of discovering new crops for agriculutral--not simply new uses for old crops like corn and wheat. Less then 1 percent of some 300,000 plant species utilized in modern agriculture. Agricultural diversification means economic diversification, new businesses, more jobs.

6. Common Sense Biology - A special effort ought to be made to identify "common sense" biological strategies already available for use in agriculture, as well as a way of providing some formal recognition to public sector researchers who have excelled in such areas of research; in addition, a major inventory of "old", abandoned, or never used public sector research in all of the above areas should be made a priority.

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AGRICULTURAL BIOTECHNOLOGY:
SOME RECENT DEVELOPMENTS IN THE SCIENCE

Plant Biotechnology

Scientific advances in plant biotechnology are coming faster than many experts ever predicted they would. Scientists who once said, for example, that nitrogen fixation in cereals was "blue sky stuff", not be expected before the year 2000, now talk about the first lab tests of such plants in the 1990s.

Rice regenerated Last December, a team of researchers from the University of Nottingham in England succeeded in regenerating rice plants from single-cell protoplasts. Before this development, attempts to grow rice plants from single, non-seed cells had repeatedly failed. This ability to regenerate whole plants from rice protoplasts was hailed as a development that removes a significant barrier to genetic engineering in the cereals.

Maize EngineeredI In another biotech breakthrough that holds much significance for cereals, the January 8th issue of Nature reported that researchers at the Friedrick Miescher Institut in Basel and the John Innes Institute in the U.K., successfully moved the genes of maize streak virus into corn cells by way of Agrobacterium tumefaciens, a vector method of genetic engineering also called agro-infection. Before this demonstration, it was widely held by scientists that members of grass family were not amenable to genetic manipulation using this technique because grasses were believed to be resistant to Agrobacterium tumafaciens.

Orange Juice in Culture. Last year, in Pasedena, California, a 35 year-old USDA plant geneticist named Brent Tisserat, working in a basement laboratory, produced orange juice from test-tube cultures of orange cells. In this Pasedena laboratory, "thousands of test tubes" containing tiny plants of spinach, carrots and other crops are growing in mixtures of nutrients and hormones. Here, Tisserat has succeeded in culturing juice-producing vesicles from citrus fruits such as oranges, lemons, and citrons. According to one report on this work, the juice that has been extracted from the plants in this cell-culture system is "chemically similar to what is squeezed from tree-grown fruit". (Flynn, 1986).

In the case of oranges, the juice-sac cells have been surgically removed from mature fruit and placed in a tissue culture medium where they remain alive for as long as 8 months,

approaching the size of cells found in tree-ripened fruit.

Tisserat's tissue culture work in Pasedena has attracted the attention of the citrus industry, and has been studied by Coca-Cola officials from the company's Minute Maid subsidiary. Allen V.Clark, manager of citrus R&D for Coca-Cola Co. Foods, which markets Minute Maid orange juice, says he is "awed" by Tisserat's accomplishment. In the near term, culturing citrus-juice sacs in the laboratory could advance trait selection work in the nurseries and speed up varietal development.

Dan A. Kimball, director of research for California's Citrus Producers Inc., says that the culturing of citrus juice sacs could help "standardize the entire citrus-juice industry". Others are more sanguine about the prospect of laboratory-produced juice, saying that it may take 15 to 25 years before its commercially feasible on a large scale. (Flynn, 1986).

Nevertheless, such work is moving forward, and others are culturing cocoa and cotton cells in the laboratory, and cloning all sorts of plants and tree crops for food, fiber and oil.

Listed below are some brief descriptions of work now going on in the private and public sectors in various categories of plant biotechnology research.

Herbicide Resistance. At least 30 companies and a number of univeristy researchers are working to make various crops and forest trees genetically resistant to, or tolerant of, certain herbicides which damage them. (see Table __)

Disease Resistance. Monsanto, in work with Washington University researchers, has genetically engineered resistance to tobacco mosaic virus into tobacco and tomato plants. Atlantic Richfield's Plant Cell Research Institute has developed some disease-resistant onions using protoplast fusion techniques.

Food Processing Traits. Campbell Soup and Heinz are working with biotechnology companies to give commercial tomato varieties a greater "high solids" content.
Frito-Lay is doing the same thing with potatoes. In 198_, Kellogg had a research contract with Agrigenetics to work on developing hihg-yielding, hard starch corn lines. As of 1984, Agrigenetics was working to develop a high protein wheat ideally suited to the baking industry, and one that would produce a flour that will absorb water 30% faster than the flour made from other varieties. Under a research contract with McCormick & Co., Native Plants, Inc., is using molecular and cell biology in researching

unspecified seeds and plants used in food seasonings.

Vegetable Oils. A number of compànies, including Lubrizol, Unilever, United Fruit, Calgene, ARCO/PCI and others, are known to be interested is using recombinant and tissue culture technologies to increase or otherwise alter the quantity and quality of oil yields from crops and trees such as cocunut, palm, cotton, rape

Protein Improvement--Feed. Molecular Genetics is working on developing high-lysine corn varieties. Sungene Technologies Corporation of Palo Alto is screening the corn germplasm of Crow's Hybrid Corn Co. (IL) for high-lysine mutants. Sungene plans to use protoplast fusion and/or gene splicing to develop new hybrid, high-lysine corn lines from any mutants it discovers.

Medicinal Products.

Forest Products. Weyerhauser has been using tissue culture techniques to develop strains of Douglas Fir and Loblolly Pine.

Livestock Biotechology

Just as the new biotechnologies have transformed the U.S. seed industry and plant sciences research, new bio-engineering processes have also changed the livestock industry, and the science of breeding and protecing farm animals. And just as changes in plant biotechnology and crops genetics have drawn a number of major corporations into those fields, a similar pattern of corporate investment and research has come to the field of animal science. Yet in one sense, the private sector presence in livstock biotechnology has benefited much more substantially than those in the plant sciences industries, primarily because of the longer public invesetment in animal and mamalian cell resarch related to cancer studies.

In a recent FDA-commissioned study, entitled, "Emerging Developments in Biotechnology", some 92 firms were identified pursuing 171 separate veterinary biotechnology projects in the U.S. Among the noted firms are: W.R.Grace, Genentech, Biogen, Upjohn, Syntex, Amgen, California Biotechnology, TechAmerica, and others. In addition, corporations as diverse as Kodak, Burroughs-Wellcome, Unilever, SmithKline-Beckman, Akzo, and Diamond Shamrock are also involved. Experts polled in the FDA study predict that more than 200 distinct veterinary products and

processes can be expected within the near future, with more than half achievable within the next 18 months.

Kidder, Peabody & Co. has reported that new biotech-made products such as bovine growth hormone, porcine growth hormone, bovine lympokine cocktail, an array of new animal vaccines, bovine interferon, and others may find their way to market during the 1987-1989 period.

Amgen, Inc., a California biotechnology company, is working on consensus interferon for cattle shipping fever and poultry somatotropin for improving poultry breeding stock. Embrex, Inc., of North Carolina is working on ways to administer vaccines and antibiotics to turkey and chicken embryos. Integrated Genetics, Inc., of Framingham, Mass., is using recombinant DNA techniques to help farm animals reproduce more rapidly.

Several companies and universities are researching ways to genetically engineer growth and other traits directly into farm animals via embryo engineering. Work is being conducted on embryos at the one-cell stage, where cloned foreign genes governing various traits can be micro-injected into the pronuclei. The genes for growth hormone, prolactins (lactation stimulation), digestive enzymes, and interferons are some of the likely candidates.

Others are researching the twinning gene in cattle, the use of human growth hormone gene in cattle and hogs, and the gene in sheep that makes certain breeds produce multiple births routinely. Still others are considering the possiblity of modifying the digesting-aiding bacteria that live in the stomachs of ruminant livestock -- a few with the idea of giving these microbes the ability to digest lignin, the protein that is a major structural component of wood.

Porcine Somatotropin

A genetically engineered swine growth hormone, called porcine somatotropin (PST), may reach the market by 1988. Research at the Pennsylvania State University has found that PST reduces fat content by some 70%, and may reduce the amount of feed needed by 25%. Faster weight gain has also been recorded in experimental use at Cornell. BST is estimated to cost $4 per treated pig at the farm level. Four corporate/biotech "teams" will compete for the estimated $300 million-a-year PST market in the U.S.-- International Minerals & Chemicals Corp /Biogen, Monsanto/Genentech, SmithKline-Beckman/Amgen, and American Cyanamid / BioTechnology General.

Vaccines

Worldwide, there are more than 20 billion farm animals susceptible to disease that vaccines could be used to treat or

prevent. In the U.S. alone, annual losses from animal diseases are estimated at $17 billion. Not surprisingly, there is a long list of companies conducting research on vaccine development. Hoechst and International Minerals & Chemicals Corp are working on a vaccine for hoof & mouth disease; Molecular Genetics has plans to develop and market as many as 30 different livestock vaccines. At least three genetically-engineered livestock vaccines for treating pig and calf scours have already been approved for use, as has one for pseudorabies in pigs.

Feeds & Feed Improvement

H. J. Heinz, Kodak and Monsanto have each made forays into biotechnology from the stanpoint of animal nutrition and/or improving feeds. In May 1984, for example, H.J.Heinz signed a three-year contract with BioTechnica International to pursue, among other things, "products of interest to the livestock feeding industry".

In July 1984, Kodak announced plans to build a multi-miliion dollar animal nutrition research center in Tennese. Two years later, in October 1986, Kodak entered into a four-year $20 million cooperative research agreement with Molecular Genetics, Inc of Minnesota to focus on the development of products for the "health, nutrition and productivity of animals".

Product "Synergy"

The feed and animal drug industries have an obvious stake in the genetic make-up of farm animals that need to be fed and/or treated . Some major companies--such as W.R.Grace, Cargill, Upjohn, Merck, Pfizer, Perdue and others-- have fully entered or have dabbled in the livestock genetics business, and are quite aware that changes in the the genetic make-up of farm animals can change feeding and treatment strategies.

In testimony before the House Science and Technology Oversight and Investigations Subcommittee in 1982, Robert Zimbelman, then the manager of experimental sciences for the Upjohn Company, explained: "Obviously, both the feed industries and the animla drug industry have a stake in the genetic makeup of the animals to be fed or treated and how this might change in the futrure". He added that alteration of the genetic basis of food producing animals could influence their response to required nutrients, their efficiency in the use of nutrieints, or their suceptibility to diseases. Zimbellman also added that drug and feed companies not then in the animal genetics business needed to begin thinking about doing so for two reasons: as a new business opportunity for selling animal products to the world, and as a "defensive mechanism" for survival of thier existing businesses.

BIOTECHNOLOGY COMPANIES & MAJOR CORPORATIONS
WORKING IN LIVESTOCK GENETICS AND/OR VETERINARY BIOTECHNOLGY

Advanced Genetic
Research Institute (CA)
Ambico (IA)
American Cyanamid (NJ)
American Qualex (CA)
Amgen (CA)
Animal Vaccine
Research Corp (CA)
Antibodies, Inc (CA)
Applied Genetics (NJ)
Atlantic Antibodies (ME)
Bethesda Research Labs (MD)
Bio-Con, Inc. (CA)
Biogen, Inc. (MA)
Biotechnica Int'l (MA)
Bio-Technology General (NY)

Biosyne Corp. (TX)
California Biotech (CA)
Cambridge Bioscience Corp (MA)
Centuar Genetics Corp (IL)
Cetus Corp. (CA)
Chiron Corp. (CA)
DeKalb-Pfizer Genetics (IL)
Diamond Laboratories (IA)
Diamond Shamrock (OH)
Dow Chemical (MI)
Embrex, Inc. (NC)
Enzo Biochem, Inc. (NY)
Genentech, Inc. (CA)
Genetic Engineering, Inc.(CO)
Genetic Replication
Technology (CA)
Genetics Int'l, Inc.(MA)
Genex Corp. (MD)
W.R. Grace & Co. (MD)
Granada, Corp. (TX)
Immuno Modulators Labs (TX)
IMC (IL)
Indiana BioLab (IN)
Integrated Genetics (MA)
Eastman Kodak (TN)

Lipsome Co. (NJ)
Lipsome Technology (CA)
Merck & Co. (NJ)
Miles Laboratories (IN)

Molecular Genetics, Inc. (MN)

Monsanto Co. (MO)
Multivac, Inc. (CA)
Neogen Corp. (MI)
Norden Laboratories (NE)
Novagene
Pfizer, Inc. (NY)
Repligen, Inc. (NY)
Ribi Immunochem
Research, Inc. (MT)
Rio Vista Int'l, Inc. (TX)
Salk Institute Biotech/
Industrial Associates (CA)
Schering-Plough Corp (CA)
SDA Biotech Corp. (OH)
SmithKline-Beckman (PA)
A.E.Staley (IL)
Symbiotex Corp. (CA)
Synergen (CO)
Syngene Products
& Research Inc. (CO)
Syntex Corp. (CA)
Syntro Corp. (CA)
Unigene Laboratories (NJ)
Upjohn Co. (MI)

Others see possiblities for "product synergy" with particular breeds, or among and between products such as vaccines, hormones, feeds, and antibiotics. For example, Unilever's Philip Porter explains that "in modern agricuture, with its intensive rearing practices, there is a synergy between antibiotics and vaccines that has not yet been exploited."

THE USDA/LAND GRANT FUNDING SYSTEM

Public funds for agricultural research in the United States today come from both federal and state governments.

At USDA, funds are allocated for research in three ways: 1) through the Agricultural Research Service for in-house research; 2) through the Cooperative State Research Service; and 3) through the Office of Grants and Program Ssystems, for competitive grants funding.

ARS funds are used to sponsor in-house agriculutral research. ARS funds are, in turn, allocated among 140 research facilities nationally. ARS research focuses on agriclutral problems of a regional, national and international significance.

Funds allocated by the Coooperative State Research Service are distributed on the basis of a formula incorporating each state's farm and rural population. Research sponsored by CSRS is accomplished largely in state agricultural experiment stations and colleges of veterinary medicine, which are part of the land grant universities. This research can be directed at local and rgeional problems, as well as national and international concerns. Under the state-matchiong formula in 1985, states appropriate about $3.50 to their agricultural experiment station for every $1.00 in federal funding (NAS, 1987). State legislatures together appropriate some $700 million annually for the state agriculutral experiment stations.

Competitive grants funding, distributed through USDA's Office of Grants and Program Systems (OGPS), is a relatively new USDA program, first established in 1978. USDA competitive grants money is not restricted to publicly-supported research institutions or universities.

At the federal level, NIH, NSF, DOE, AID, and the Public Health Service also provide funds to scientists working at the land grant universities, state universities, and the agricultural experiment stations.

Today, the state and federal government together spend about $1.9 billion on agricultural research annually.

Each of these public-sector funding sources has its own unique history, and each has spawned its own "turf", its own constituency, and to a lesser degree, its own political champions.

Non-Corporate Private Sector Funding in the Land Grants.u
Some funding to the land grant universities and agricultural experiment stations also comes from non-corporate private sources, including foundations, trade associations, and commodity organizations.

There are some 400 American foundations that award grants of $5,000 or more to agricultural researchers. (OTA, Dec. 81) The nature and purpose of these grants vary with the interest and purpose of the foundation.[1] Compared with the amount of funds available from public sources, however, the amounts provided by most of these foundations are modest.

1

One example of a grant from a private foundation is that recentl made by the McKnight Founadation of Minneapolis, a foundation with $350 million in assests from the 3M Corporation's long-time executive William McNight. In 1982, the foundation announced its plans to spend $2 million a year for the nxt 10 years on basic research and granduate education in plant biology. The bulk of this money, targeted for about a half dozen universities with interdiciplinary research teams focusing on plant genetics , will be made in blocks of up to $300,000 a year and will support doctoral and post-doctoral research. Another ten grants of $35,000 per year for 3-year periods will be awarded to university scientists conducting basic research in plant biology related to agriculture. Helping the McKniught Foundation put its program together in 1982 was Richard S. Caldecott, dean of bilgical sciences at the University of Minnesota. Cadecott noted in 1982 part of the reason for the Foundation's interest in plant bioology: "NIH has brought about advances in animal science by paying atention to basic biology. USDA hasn't done that in plant science, and they are seriously lagging behind". (Norman, 1982)

SOME STATE PROGAMS WITH AN AGRICULTURAL BIOTECHNOLOGY RESEARCH COMPONENT

"With appropriate resources, Ohio State has the opportunity to become the Silicon Valley of agricultural biotechnology."

- Prof. Floyd Schanbacher
Animal Biotechnology Program
Ohio Agricultural Research and Development Center
Ohio 21, March 1987

Ohio. Ohio State University has created its "Ohio 21" program, described as "a bold, ambitious and assertive program to position Ohio favorably for the challenges of the 21st century".

In a brief promotional pamphlet prepared on the program--a pamphlet, in fact, well-suited for lobbying state and national pollitical leaders-- the rational behind the new agriculutral research initiative is laid out in very pro-Ohio tones:

> Agriculture provides Ohio with a unique opportunity to invest in its economic development. Ohio 21 is a well-thought-out, long-range plan to bring about positive change, not only to farming and the agricultural industry of the state, but to the nonfarm sectors as well. After all, agriculutre is a $43 billion industry--the state's largest...
>
> When fully implemented...Ohio 21 will put Ohio into a commanding position as the leader in food and agricultural economic development in the 21st century.
>
> The State of Ohio is in a pivotal position in this era of advanced technology. Publicly funded research thrusts and expanded technology tranfer through Extension will build on Ohio's great agriculutral resoruces. These programs will enable Ohio to lead the nation toward a new new era of unparalleled

economic growth and prosperity along with imporved personal health and family stability.

By meeting the challenge of Ohio 21, the political leaders of Ohio will maximize the use fo the state's resoruces to meet the manifest needs of its people.

North Carolina. In 1981, The North Carolina Biotechnology Center--now a non-profit corporation--became the first state-sponsored venture in biotechnology. The task of the Center is to encourage statewide research and commercial development in biotechnology. In the latest legislative session the Center received $14 million in funding which is used throughout the state for biotechnology research, faculty recruitment, and public education.

According to the Center's literature, "All programs of the Center encourage statewide collaboration between universities and industry, and are designed to further research significant to the development of useful products."

One of the Center's programs focuses on agriculture and forestry, two of North Carolina's most important industries. A fellowship program has been established in plant molecular biology by the Center to train graduate and post graduate students at Duke, UNC and NC State. In 1984, Ciba-Geigy and R. J. Reynolds each committed $120,000 for this program over three years.

Washington. In July 1983, the state legislature passed the Washington High Technology Education and Training Act, which among other things, created the Washington Technology Center (WTC). The WTC is currently located at the University of Washington in Seattle.

The WTC is a joint government/university/industry effort consisting of $3.6 million in 1985-87 appropriations from the state, to be matched by any combination of federal and/or industry sources. The purpose of the Center is to promote high- technology research, higher education, and development in Washington state in several areas: advanced electronics, biotechnology, plant genetic engineering, computer systems, robotics, and advanced materials. Joint university-industry research is encouraged.

Participating universities include: the University of Washington, Washington State University, Seattle University, Gonzaga University and the state's regional universities. There are a number of "industry partners", including Abbott Labs, ALCOA, Boeing, Chevron, DuPont, IBM and Weyerhaeuser.

The Center's 25-member board of directors consists of 14 representatives from industry and 11 from academe. Research advisory committees consist entirely of university representatives.

Biotechnology research has received about $3 million in 1985-87 funding from all sources, with projects in medical, crop, livestock, and forest biotechnology in evidence.

In March 1984, the WTC funded its first research projects at Washington State University in livestock and plant biotechnology. In June 1984, Weyerhaeuser became the first company to fund a collaborative reserch with the Center, providing $50,000 in support of a project in forest products biotechnology. Weyerhaeuser is also interested in developing bacteria that will transform paper-making by-products into commerically valuable chemicals.

The biotech program in crops consists of work to devise gene transfer systems for monocot plants, and the development of diagnostic antibodies for use with crop plants. WSU researchers are focusing on mobile genetic elements in barley to come up with a recombinant technology for monocots. Work in forest biotechnology consists of the genetic engineering of trees such as poplar, Douglas fir, and Western hemlock as well as reseaerch on microbes used in forest-products processing and by-products manufacturing.

Wisconsin. A special effort in biotechnology in the food processing and agricultural industies is also underway in this state, in which officals have explored the the possiblity of encouraging public pension funds to invest in biotechnology ventures. In fact, some ventuer capitalists, such as James Vaughn, vice president of the Milwaukee-based Lubar & Co., believe that Wisconsin has to go "an extra mile" with inducements to overcome the anti-business legacy of former populist governor Robert La Follette.

In this spirit, the state has, in recent years: eased the stringency of its security regulations, making it easier for companies to raise money; reduced the tax load on industry by indexing the state income tax to inflation; and adopted the federal approach to capital gains taxation, over-turning the sate's former taxation of capital gains as ordinary income. Wisconsin officials have also instructed their universities to be more aggressive in the area of technology transfer to industry, and have encouraged their university deans to provide industry ready access to their campuses for research assistance and consultation.

RECENT ADMINISTRATION & CONGRESSIONAL PROPOSALS
FOR ADDTIONAL AGRICULTURAL BIOTECHNOLOGY RESEARCH FUNDING

White House "Centers-For-Plant-Science" Proposal

In April 1986, the Ad Hoc Working Group on Plant Science--consisiting of representatives from the National Science Foundation, USDA, DOE, and OSTP-- prepared a paper for the President's acting Science Advisor, John P. McTague entitled, "Science and Technology Centers for Plant Science". This paper is the background document for an Administration proposal calling for the creation of several multidiciplinary plant science research centers at univerisites that would focus on the following areas of research and training: 1) rhizosphere dynamics & microbial ecology, 2) plant biotechnology, 3) complex carbohydrates, 4) ecological processes, and 5) systems research & analysis.

This proposal envisions initially, a $10 million-a-year, joint funding effort by USDA, NSF and DOE utilizing a competitive grants/peer review process to allocate the center funds. The plan, beyond that is described as follows:

> The Working Group on Plant Science concluded that the first year of the program should be budgeted modestly at $10 million. This would provide for the stablishment of several centers--perhaps five or six--each at an average funding level of $1-2 million. A five-year budget increaing annually by $10 million would call for an obligation in year five of $50 million and a cumulative investment of $150 million over the period to establish not more than 20-25 centers. Not all costs need be incurred by the Federal government if collaborative funding can be arranged between it, local and state governments, private foundations and industry.

According to the report, the centers "should establish foci for industrial, other private sector, and local and state government participation". Such partnerships would encourage cost sharing, the paper explains. "It is expected", the paper continues, "that the centers would form, wherever possible, research and training relationships with existing facilities and expertise in laboratories such as thos of the Agricultural

U.S. FEDERALLY FUNDED RESEARCH IN BIOTECHNOLOGY[1]
Fiscal Years 1984-87

	Amount of Funding (millions of dollars)			
	FY 1984	FY 1985	FY 1986 (est.)	FY 1987 (budget est.)
National Institutes of Health	$1,633	$1,839	$1,836	$1,801
Directly related[2a]	521	639	636	621
Broader science base[2b]	1,112	1,200	1,200	1,180
National Science Foundation	61	82	89	109
Department of Agriculture	39	77	74	79
Department of Energy	38	43	43	44
Department of Defense	33	34	43	49
Army	24	22	28	31
Office of Naval Research	9	12	15	18
Department of Commerce/National Bureau of Standards	1	1	3	4
Environmental Protection Agency	0	2	6	8
TOTAL	1,805	2,078	2,094	2,094

1. For purposes of this analysis, the Office of Technology Assessment's definition of biotechnology is used: Biotechnology includes any technique that uses living organisms (or parts of organisms) to make or modify products, to improve plants or animals, or to develop micro-organisms for specific uses.

2a. NIH defines directly related research as that research involving genetic manipulation, cloning of DNA, use of special techniques to isolate and detect DNA, creation of hybridomas and production of monoclonal antibodies, and computer methods used to analyze DNA and protein sequences.

2b. Broader science base research refers to that research underlying the new biotechnology and includes free-ranging investigations in genetics and molecular biology, cell biology and immunology.

Note: All dollar amounts have been rounded to the nearest million.

Source: Data was obtained from the White House Office of Science and Technology Policy and biotechnology program officials in each of the cited Departments and agencies.

Research Service and Forest Service Research, the National Laboratories and industry".

The Centers for Plant Science proposal is to be offered formally this fall by the Administration. Some FY 1988 budget recommendations are already incorporating this proposal for USDA's competitive grants program

The Harkin Bill. In May 1987, Sen. Tom Harkin (D-IA) introduced S. 970, The Alternative Agricultural Products Research Act of 1987. The purpose of the bill is to establish a 20-year, $75 million/year research effort using biotechnology to develop new industrial "end uses" for traditional agricultural crops.[1]

The bill would create a 9-member Biotechnological Research Board in USDA to be administered by the Assistant Secretary and include 3 members apointed by the Assistant Secretary, 2 members appointed by the National Science Foundation, 2 members appointed by the Secretary of Energy, and 2 members appointed by the Secretary of Commerce. This bill also makes allowance for the formation of consortia between public and private colleges and universities; private research facilities and personnel;

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1 At hearings on his bill May 15th, Sen. Harkin said:

> In the long-term, the agricultural problem is more than a question of production levels or of export markets. It is also a problem of insufficient diversification. We lack diversification in many agricultural areas of the country where only a few commodities are produced. We also lack diversification in the range of end uses for which are agricultural feedstocks might be used...
>
> ... We need our existing commodities "bio-engineered" so that the range of new products capable of being produced can be expanded several fold.
>
> I can see a day when new plants will be designed for specific end uses, or process conditions. I believe it is possible with the mapping of genetic structures of corn, what, soybeans and other feedstocks, that we will be able to bio-engineer new industrial oils, new proteins and new chemicals. All of this diversification is necessary as a precursor ro a competitive agricutural system....
>
> It is time to greatly expand plant biotechnology and bio-processing research...

state agricultural experiment stations; and federal research laboratories.

The Harkin bill was opposed by USDA and NSF at the bill's hearings, and was supported by the Industrial Biotechnology Association, Pioneer Hi-Bred International, Inc., the Midwest Plant Biotechnology Consortium, Calgene, Inc., the National Corn Growers Association, Purdue University/Indiana Agricultural Experiment Station, Ohio State University, and Iowa State University.

USDA -- BACKGROUND TO THE COMPETITIVE GRANTS FIGHT

One of the first critical reviews of the USDA-led agricultural research system came under the name of the "Pound Report", a 1972 National Academy of Sciences study headed by University of Wisconsin biologist Glenn Pound. The Pound Report criticized the USDA research system as sluggish, and argued that public agricultural research had become highly insular and divorced from the fronteirs of knowledge in the basic biolgical sciences. (NAS, 1972)

Two years later, in a more popular treatment, J. and A. Mayer, writing in Daedalus under the titile, "Agriculture, The Island Empire", argued that agricultural science was isolated from Amrican academic life and no longer on the leading edge of scientific progress. (Mayer & Mayer, 1974).

Following the 1974 World Food Conference in Rome--which was a response to the world food crisis of 1972-73-- President Gerald Ford asked the National Academy of Sciences to prepare a report on how the United States could mobilize its R & D effort to address the problems of world food supply. The NAS study, entitled, The World Food and Nutrition Study, recommeded increased funding for research in plant genetics, biological nitrogen fixation, photosynthesis, and disease and pest-resistance crop breeding.

In 1975, a conference held at Boyne Highlands, Michigan, sponsored by the Michigan State University Agricultural Experiment Station and the the Charles F. Kettering Foundation, also underscored the point that greater inputs of fundamental biological science were needed to increase crop productivity. Momentum began building within the scientific community for changes in the agriculutral research system.

Shortly after the Boyne Highlands conference, Rep. Ray Thorton (D-AR) began working on a congressional measure that incorporated the suggestions of the NAS, Boyne Highlands and other reports calling for a special grants process in USDA to fund the basic research. In 1976, Rep. William C. Wampler (R-VA) introduced H.R. 11743 to establish a basic research grants program in USDA, and this measure was incorporated into the 1977 farm bill, The Food and Agriculture Act. (Krogmann & Key, 1981).

Initially, the competitive grants approach to agricultural funding, was not well received by many land grant universities and agricultural experiment stations-- interests who perceived this program to be a threat to their formula-based funding. And there were other factors as well. For example, according to one account:

> In the late 1970s, the Agricultural Research branch suffered reductions in personnel ceilings. The Cooperative Research branch, whose funds when distributed to the Agricultural Experiments Stations are often used to pay salaries of researhcers, has not received budget increases to keep pace with inflation. It was possible to assume that the new activity was being created at the expense of salaries of loyal employees. (Krogmann & Key, 1981).

Between 1978 and 1980, bitter fights over funding this program ensued in the Congress. Authorization was made for appropriations up to $25 million for the program in 1978, with $5 million increases in the subsequent 3 years and a $10 million increase for 1982, making for a total of $50 million. However, due to political differences in the Congress and the opposition of some established agricutural interests, the competitive grants program in USDA emerged with compromise funding. Actual appropriations were short of what the White House wanted: appropriations of $15- million-to-$16 million were all that came out of Congress during the 1978-1982 period. But other changes were on the way.

The 1982 Winrock Report. With the arrival of the Reagan Administration in 1981, the USDA system of agricultural research came in for a new round of review. One of those focusing on agriculture was Dennis Prager, a PhD physicist who began working at the White House science office as a policy analyst during the Carter Administration in 1978. Prager volunteered to take on the agricultural issue during the competitive grants fight.

Reflecting on his early role in the White House in November 1982, Prager told Chemical & Engineering News: "I found the agricutlural research community to be complicated, factioned, and not like any other research group. Even if you knew a lot about NIH and NSF, you still wouldn't know anything about the ways of agricultural research. So I immersed myself in all aspects of agriculture and found myself giving talks all over the country to willing audiences". (Lepkowski, 1982)

Prager began to become concerend with the quality of research at the land grants and the experiments station, and the system's lack of interest in taking advantage of research going on outside of agriculture.

At a May 20, 1982 briefing of the White House Science Council, Prager outlined the background on the land-grant situation as he saw it. He told the Council that about 10 to 12 of the nation's ag schools were in tune with modern science. The rest, he suggested, were isolated from mainstream science departments at their instititutions. He also explained that

the land grant system increasingly focused on short-term applied problems of direct concern to state farming communities, to the neglect of scientitifc developments that have proven revolutionary in other areas of the life sciences. (Greenberg, 1980)

At the briefing, Praeger continued to offer his personal view of what was happening in the land grant system. He charged that the land grant system was not adaptaing well to the new biology, and "tended to circle the wagons" as compeititon for federal research dollars increased rather than finding a way to partake in advanced research. Nor had the land grants, in Prager's view, adapted well to outside institutions moving to the forefront of biological sciences. He suggested there would be a problem in adapting this traditional system to the new biology and the new ways of research. "A look at the really exciting biological reesearch in this country that is applicable to agriculture", Prager then told the Council, shows that "a relatively small percentage of it goes on in the land-grant system".

But Prager noted that a number of the land-grant schools were "really excellent"--among them, the University of Wisconsin, the University of California, and Cornell.

"I began to feel there were problems that needed to be addressed, and then began running into tremendous hostility from the land grant community, especially in the Midwest" (Lepkowski)

"They are well organized, conservative, and paranoid. Oncve they understand where the momentum in going, they try to spot the people behind it an rub them out. They are saying I'm trying to destroy the agricultural research system. They feel that the system is over 100 years old, its productive, and doesn't need change". (Lepkowski)

"The bottom line is that if you draw a fence around ARS and the experiment stations, they are not producing enough basic knowledge to sustain (the) productivty of AMerican agriculture" (Lepkowski)

One of the land grant officials to object to Prager's criticism and the Winrock study in 1982 was John Dunbar, then dean of agriculture at Kansas State University and acting head of the agricutural experiment station. Dunbar felt the Winrock report was born, in part of ignorance, and detachment from agriculture.

"No one knows what they're talking about when they say we don't do basic research here. Nor do the same people know anything when they say we don't do peer review at places like

this', said Dunbar in 1982. Hatch funds at Kansas State are distributed by in-house review committees. Those doing good research get funded, the others don't. Some younger faculty then were out-earning older faculty, reflecting more agressive research. (Lepkowski).

In June 1982, OSTP and the Rockefeller Foundation organized a meeting of 15 individiuals representing a handful of universities, corporations, and the USDA. This meeting was held at the Winrock Conference Center in Arkansas, and resulted in a brief report entitled Science For Agriculture, which sharply criticized the USDA system, and advocated an expansion of the peer-reviewd competitive grants approach, and less formula-based funding.

The Winrock Report charged the USDA with exerting ineffective political leadership; using a piecmeal approach in basic agricultural research; failing to fund the most important areas of science; losing its place on the "cutting edge" of agricutural science; and distributing federal funds "largely on the basis of geopolitics rather than need or expected return". The report, in the eyes of many, invited USDA to prune dead wood from the system, and suggested that Congress consider selling some of the agriculutral experiment stations to the states or private industry.

One idea growing out of the debate that ensued with the Winrock report was that of forming a National Institue of Agriculture, created along the lines of the National Institutes of Health. The idea found some support with administrators from a few of the larger universities, and representatives of some major corporaitons interested in agriculutral research.

Today, there is still some tension between the competetive grants and formula-funding camps in the agricultural funding wars. But accommodations have been made that may only last until new funding struggles emerge. For example, according to one recent report: "...the state agricultural experiment stations encourage efforts to expand federal competitive grants programs in the agricultural sciences. New grant monies, however, must not be secured at the expense of the SAES base program..." (ESCOP, Research 1984, p.16)

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Also in May 1982, the USDA began running political loyalty checks on department scientists and university scientists who were providing expert advice to the department in its Competitive Grants Program. James Handley, then an assistrant to Scretary of Agriculture John Block, was quite direct about the need for the new policy. "In my opinion", he said, "scientists should be checked for philosophical compatability (with the Administration's views). We like to believe we have a more conservative philosophy than the last administration. We would

like to appoint people who share our political views". Handley further explained that given two scientists holding equal credentials but differing political views, it was the department's job to appoint the person with the more politically compatible views. After a newspaper story and controversy ensued, this practivce was halted. But prior to that, the names of scientists nominanted for USDA review panels were being pased to the FBI for security checks and then to the Secreatary of Agriculture's office for political checks. (Hilts, 1982).

AGRIBUSINESS CONSOLIDATION

A Sampling of Mergers & Acquisitions in Food & Agriculture

Meat Packing/Processing. In recent years, there has been considerable consolidation throughout livestock agribusiness. In 1981, for example, Occidental Petroleum acquired Iowa Beef Processors, the nation's largest beef packer. Last year in the poultry industry, Tysons acquired Lane Processing of Grannis, Arkansas.In turkey processing, Hormel has acquired Jennie-O-Foods, the industry's 3rd largest processor. In hog processing, Con Agra acquired a Kentucky-based firm, Webber Farms. In 1987, the Supreme Court cleared Cargill's acquisition of Spencer Beef, making Cargill the nation's largest beef packer. Cargill already owns MBPXL, the nation's 2nd largest beef packer, which it acquired in 1978.

Livestock Genetics/Veterinary Services. In the livestock genetics/veterinary field today, firms such as Cargill, Occidental Petroleum, W.R.Grace & Co., and SmithKline-Beckman each have operating businesses. W.R. Grace owns American Breeders Service of Wisconisn, the nation's largest dairy breeder. Merck & Co. owns Hubbard Farms, one of the nation's largest breeders of broiler chickens. Others, like Perdue, have their own in-house genetics research operations. Still others like Land O' Lakes are engaged in hog breeding and embryo transfer. Upjohn and DeKalb AgResearch are involved in poultry breeding.

Seed Company Takovers. Since the late 1960s, seed companies have been targets for corporate investment. Today, at least 120 U.S. seed companies are now owned by larger corporations. Monsanto, Ciba-Geigy, Cargill, Pfizer, Elf Aquitaine, ICI, Upjohn, Royal Dutch-Shell, Lubrizol, Sandoz each own at least one seed company, and some own as many as eight. Many of these same corporations, through their seed-company subsidiaries, also hold a majority of U.S. seed patents.

Although seedsmen often talk about "the hundreds of seed companies" that exist, industry analysts typically point to about 80 "fully integrated" seed companies in the U.S. that include the four principal seed trade functions: research, production, conditioning and marketing. And it is these firms that have been the target for takeovers; the ones with germplasm, breeding programs and breeders.

Fewer Pesticide Companies. Most pesticide R&D in the U.S. today takes place at about 20 multinational corporations that manufacture active ingredients for pesticides (Delaney). The conventional economic wisdom in the industry these days is that you have to have $1 billion in annual sales and $100 million in annual R&D to make it as an agrichemical company. A shake-out is currently underway in the industry, with some of the majors expanding their position through acquisitions.[1]

Du Pont, for example, has been fairly active in the last few years buying up agrichemical divisions of other companies. In 1981, it acquired a French ag chem company; in 1984, a West German operation; and in 1986, it acquired the U.S. ag chem operation of the Shell Oil Company.

In January 1986, Sandoz paid $225 million for the Velsicol Chemical Corp agrichemical unit of Farley/Northwest Industries. Sandoz officials said the addition of the Velsicol unit marked an "important strengthening" of their U.S. business. By June, Sandoz had combined the Velsicol unit with its Zoecon division, acquired from Occidental Petroleum in 1983.

In June 1987, Imperial Chemical Industries, Great Britain's largest company, announced it would spend $1.7 billion to acquire the Westport, CT-based Stauffer Chemical Company from Unilever. Market analysts noted that ICI would pay 18.5 times earnings for Stauffer's. But the move would make ICI

Fertilizers. In the fertilizer business, too, there has been consolidation. In 1981, Elf Aquitaine, the largest oil/chemical company in France, acquired Texasgulf, Inc. a major producer of fertilizer. In 1982, International Minerals and Chemicals Corporation (IMC), the world's largest private producer of phosphate rock and potash, acquired the Iowa and Illinois fertilizer and ag chem outlets of the First Mississippi Corporation. IMC has also acquired a 50% interest in a Korean fertilizer company.

In July 1986, Occidental Petroleum acquired American Cyanamid's North American dicalcium phosphate business, which includes plants in Iowa, Missouri and Nebraska.

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1 In other cases, some major agrichemical producers, such as Monsanto and Sandoz, have begun joint marketing ventures around existing products. In July 1986, Sandoz and Monsanto agreed to develp and market new combinations of their existing herbicides--Sandoz's dicamba and Monsanto's glyphosate. "We expect that the glyphosate/dicamba products to be commercialized by Monsanto will broaden the use base for both products and provide significant growth for dicamba outside of our traditional markets," said Sale A. Miller, president and CEO of Sandoz Crop Protection Corp.

Ag Biotechnology. Some chemical and agribusiness companies have also begun to acquire, or joint venture with, biotechnology companies. In September 1984, Lubrizol spent $110 million to acquire Agrigenetics, an agricultural biotechnology company that also had become the nation's 6th largest seed company by way of 10 acquisitions. W.R. Grace has a 51% share in Agracetus, a joint venture with the Cetus Corporation. And a number of major agribusiness companies have equity in, or contracts with, biotechnology companies. (Doyle, 85).

Public and Private Sector Roles in the Funding of Agricultural Biotechnology Research

by

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The second author started assisting the first author on writing this report after the untimely death of Dr. Shaw on May 20, 1987.

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INTRODUCTION

Agricultural biotechnology research performed in the public sector and private sector has different long term objectives. The objective of the private sector research is to develop products that are profitable to the company that paid for the research. The public sector research is undertaken to benefit the public that pays for the research. The purpose of this paper is to examine the agricultural biotechnology research agendas of both the public sector and private sector and to evaluate how extensively the objectives of this research have been influenced by the source of funding. Not surprisingly, there has been substantial overlap between the research agendas of these two sectors. There are indications that the extent of this overlap is presently and will continue to change. Because of the changing relationship, the public sector can no longer rely on the private sector to perform substantial fundamental research. Accordingly, agricultural biotechnology research performed by the public sector will need careful management so that its research priorities benefit the public and the vital agricultural industry of the US.

This discussion of research agenda in agricultural biotechnology will cover the range of activities involved in the complete process of innovation from fundamental research to commercialization (Clogston, 1987).

BACKGROUND

Historically, public biotechnology research has influenced the private sector research agenda. Unquestionably, the early leadership by the United States in the biotechnology industry would have been extremely difficult if the research discoveries and the trained research personnel were not available to companies in the US. Basic research, that research undertaken to create new fundamental knowledge, for example, the discoveries by Cohen and Boyer that are fundamental to recombinant DNA techniques were critical in the development of biotechnology, is primarily supported by public funding. Usually, the timing and financial reward from basic major discoveries are not predictable. This uncertainty makes favorable industrial evaluation of a basic research investment unlikely and helps to explain why through out industry less than 5% of the expenditures for industrial research are for basic research (NRC, 1987). It is very important to emphasize this because adequate public funding for basic research is essential and must continue.

The agricultural research enterprise in the United States reflects a long tradition of government and industry cooperation. Research by the USDA is the pioneer that established the Federal government's role in research and education as practiced now by many federal agencies for

example, NIH and NSF. It is interesting that in 1939 approximately 80% of Federal government research was for agriculture while in 1985 agricultural research was less than 2% of Federal government research budget. Analyses of the impact of publicly supported agricultural research indicate that the public has benefited from this investment in agricultural research (Evenson et. al., 1979; Ruttan, 1982). Evensen et al, (1979) analyzed many of these studies and estimated for US agriculture the annual internal rate of return at 110% for science-oriented agricultural research for the period 1927-1950 and 95% for technology-oriented agricultural research during the same period. These returns on publicly supported research would be attrative to any private company. During 1948-1971, the annual internal rate of return for farm management research and agricultural extension is estimated at 110% and demonstrates the value of technology transfer on a local level for agricultural research results. The public has benefitted from an abundant and low cost food supply.

In spite of this successful history and pioneering precedent, the public benefit from publicly supported agricultural biotechnology research needs to be assessed and considered as this exciting frontier from agricultural biotechnology emerges. This is especially important because the impact of biotechnology on agriculture is projected to be second only to medicine (Busche & Hardy. 1985). One way to assess the

public benefit is to examine the agricultural biotechnology research agendas in the public and private sectors and to examine in more detail the convergence and divergence of these agendas over the last several years and to project changes that could happen in the future. One of the first difficulties encountered in this examination is the use of a uniform definition of biotechnology. The broadest definition of biotechnology is the application of biological systems and organisms to technical and industrial processes and encompasses fish farming, nitrogen fixation by microorganisms and can even include the production of alcoholic beverages 6000 years ago by the Babylonians (Miller & Young, 1987). Often, for budgetary purposes this broadest definition is used because it sells well to both industrial management and government budget makers. At the other extreme, biotechnology is defined as genetic engineering using recombinant DNA techniques. This narrow definition is used when there are regulatory considerations because different regulatory processes are triggered by the word biotechnology. This inconsistent use of the word biotechnology confounds a precise analysis of the agricultural biotechnology research agenda as performed in the public and private sectors. Further, the collection of information in the public sector is inconsistent (NRC, 1987) and there is not comprehensive information available about the private sector. Regardless, the writers have drawn on their collective insight and experience plus published information to make relevant

observations.

PUBLIC AGRICULTURAL BIOTECHNOLOGY RESEARCH

When biotechology companies were founded in the mid-1970's, agriculture was an industry interesting to these businesses. It was a potpourri of basic knowledge that faced the biotechnology industry as it considered agricultural business opportunities. There was not sufficient basic knowlege to pursue the opportunities that could be dreamed up based on knowledge of r-DNA in bacteria like E. coli.

Because of this research deficit, it is necessary to examine how this public research agenda developed. It is reasonable to expect the USDA to have led support of biotechnology research for agriculture since USDA unequivocally has the mission to undertake research necessary to support the vital agriculture of the country. However, this public agricultural biotechnology research leadership from the USDA was inadequate during the early stages. From one perspective this is surprising since the USDA and agricultural universities have been so successful in developing plant genetics and modern plant breeding methods. Yet, from another perspective, it is less surprising because the strength of the public agricultural research system has been applied research while the USDA has been widely criticized for not performing enough basic research (Winrock

International, 1982). During the earliest stages agricultural biotechnology research was primarily basic research.

Instead of USDA leadership, there has been disperse support for research on plants and agricultural microorganisms by several Federal agencies including the USDA. Animal research has benefitted from the successful research enterprise of the National Institutes of Health as well as the USDA. Why was not there better basic knowledge for agricultural biotechnology? The answer to this question is complex and requires a more extensive analysis than is possible here. However, there are several reports which examine this extensively (Winrock International, 1982). Taking the liberty to summarize some of the critical conclusions, the following are critical factors that influence the USDA research endeavors:

- The USDA research system is diverse and complex.
- The public places a low priority on agricultural research. This is partly the result of an increasingly urban population and a decreasingly rural population and the accompanying political implications. Further, when there are food surpluses and substantial Federal subsidies for agricultural products, it is extremely difficult to convince the public and elected officials to appropriate major

increases for any agricultural research. This low public support for agricultural research contrasts sharply with the substantial public support for health related research as exemplified by more than 6 times greater Federal research expenditures at NIH than USDA, Table 1.

- There are almost level appropriations for agricultural research. This makes the development of new programs difficult when a very high % of research support is tied to existing personnel and facilities.

Inspite of this shortfall in fundamental research for agricultural biotechnology, it is important to examine relevant public research support and changes which have occurred. For this particular field, it is also very important to look at the contributions the private sector has made to new knowledge.

In Table 2, the total amount of publicly funded biotechnology research for agriculture for 1985 was $95.8 million which was approximately 38% of all agricultural biotechnology research funded in the US and only slightly more than 5% of the biotechnology research funded by NIH. This $95.8 million amount may be misleading because in Table 3 the USDA experienced a $23.5 million increase in 1985 over 1984 (NRC, 1987).

Table 1
Federal Obligations For Research and Development*
FY 1982 - 1987
(Millions of Dollars)

	1982	1983	1984	1985	1986**	1987**
DOD	20,623	22,993	25,373	29,792	33,646	40,679
(DOD)	(20,623)	(22,130)	(23,515)	(26,719)	(29,385)	(33,508)
NIH	3,941	4,353	4,831	5,451	5,611	5,271
(NIH)	(3,941)	(4,190)	(4,477)	(4,889)	(4,900)	(4,342)
DOE	4,708	4,537	4,674	4,966	4,692	4,771
(DOE)	(4,708)	(4,367)	(4,332)	(4,454)	(4,098)	(3,930)
NSF	975	1,062	1,203	1,346	1,333	1,508
(NSF)	(975)	(1,022)	(1,115)	(1,207)	(1,164)	(1,242)
USDA	797	848	867	943	923	909
(USDA)	(797)	(816)	(804)	(846)	(806)	(748)
INT	381	382	411	392	388	351
(INT)	(381)	(368)	(381)	(352)	(339)	(289)
EPA	335	241	261	320	334	310
(EPA)	(335)	(232)	(242)	(287)	(292)	(258)
AID	200	227	237	220	221	238
(AID)	(200)	(218)	(220)	(197)	(193)	(196)
Inflation (GNP) 1982 Dollars	100	103.9	107.9	111.5	114.5	121.4

* Figures in ( ) are in 1982 dollars ** Estimates

Source: Federal Funds for Research and Development, Detailed Historical Tables, Division of Science Resource Studies, NSF

TABLE 2. A Comparison of Data on Funding Levels Available for FY84 and FY85 on Biotechnology and Agriculturally Related Biotechnology Research by Selected Sources

Sponsor	Amount (millions of dollars)
AGRICULTURALLY RELATED BIOTECHNOLOGY	
USDA[a]	
Agricultural Research Service	24.5
Cooperative State Research Service:	
Competitive Research Grants Office	30.0
Hatch Act and Special Grants	18.4
SAES (nonfederal support)[b]	
State funding	17.3
Industry	5.6
Private industry[c]	150.0
ALL BIOTECHNOLOGY[a]	
EPA	1.5
FDA	2.6
NIH	1,849.5
NSF	81.6

NOTE: EPA = Environmental Protection Agency; FDA = Food and Drug Administration; and SAES = State Agricultural Experiment Stations.

[a] FY85. Competitive Research Grants Office funding includes both specific biotechnology grants and additional biotechnology-related research covered by its other grants. Funding by non-USDA federal agencies may include some agriculturally related biotechnology research. SOURCE: Government Accounting Office, 1986.

[b] FY84 data.

[c] Estimate based on data from the Agricultural Research Institute, 1985. A Survey of U.S. Agricultural Research by Private Industry III. Bethesda, Md.

SOURCE: National Association of State Universities and Land-Grant Colleges, 1985.

EXCERPTED FROM: National Research Council, 1987.

One important observation to make from this data in Table 3 is that the major response to increase agricultural biotechnology research was to dramatically increase the appropriation for the USDA Competitive Research Grants. There are many positive aspects to this increase including the funding of the highest quality research, funding of young researchers and funding at non-land-grant universities. In spite of these positive dimensions, the funding for the Competitive Grants Program has been less than needed. The original proposal for the Competitive Grants Program was for $25 million for the first year in 1978 with $5 million increases for the next 3 years and a $10 million increase in 1982. The final budgeted amount for these years was $15, $15, $15.5, $16, and $16 million. So, when the need for agricultural biotechnology research was increasing dramatically (the "first flush" of agricultural biotechnology companies was from 1977 to 1981), the Federal funding to the most responsive part of the USDA budget for this research was $77.5 million compared to the $180 million that was considered by experts as absolutely necessary. The average level of funding is another aspect of the Competitive Grants Program which is alarming. The average USDA award is $46,200 per year compared to $70,000 at NSF and $164,000 at NIH. (NRC, 1987). With these tremendous differences, the ability of public agricultural biotechnology research to attract high quality researchers will be challenged. The uncertain future funding of pre-doctural and post doctoral fellowships,

Table 3. USDA

Biotechnology Research

($ in Millions)

	FY 1983	FY 1984	FY 1985	FY 1986 Budget
ARS				
Plant Productivity	$5.9	$6.9	$8.5	$9.4
Albany Gene Expression Ctr.	(0)	(0)	(2.0)	(2.9)
Animal Productivity	6.6	6.8	7.6	7.5
Soil & Water Conservation	1.0	1.1	1.1	1.1
Commodity Conversion and Delivery	0.3	0.6	2.2	2.2
ARS Total	13.8	15.4	19.5	20.2
CSRS				
Hatch Act	8.9	9.1	12.2	12.2
Special Research Grants	1.6	3.5	3.4	--
Competitive Research Grants	8.3	9.0	29.5	29.5
All other	1.0	1.0	1.0	0.4
CSRS Total	19.8	22.6	46.1	42.1
Forest Service				
Intramural	0.4	1.1	1.0	0.9
Competitive Grants	---	---	1.6	---
FS Total	0.4	1.1	2.6	0.9
USDA Total	34.0	39.1	68.2	63.2

Biotechnology is broadly defined to include the technologies of gene transfer (genetic engineering), cell and tissue cultures (asexual propagation), protoplast fusion (asexual genetic recombination from diverse species), and embryo manipulation and transfer.

SOURCE: USDA

programs initiated in 1984, and the demands from the private sector do not enhance the prospects for a dynamic public agricultural biotechnology research community for the future. It is fair to conclude that the Federal budget making process has not benefited agricultural biotechnology research. This should be a serious concern to this nation because agriculture is a major industry in the US being responsible for 1 in 5 jobs (ARI, 1985). A startling comparision is Brazil which is investing as much per capita in agricultural research as the US (GAO, 1987). Likewise, Brazil is very aggressive in the global marketing of its agricultural products.

One positive program identified in Table 3 is the Plant Gene Expression Center which is mandated to perform interdisciplinary research on the biology of plant genes and their expression. The Center has tremendous potential to create new knowledge in this critical area. The multidisciplinary approach planned at the Center is absolutely necessary to make progress and, in fact, should correspond closely to the approach used by industry. The involvement of industry in this Center should be encouraged to mutually benefit public research and industrial research. The involvement of industry is not certain because at least 2 publicly supported research centers in plant molecular biology were not initiated because insufficient industry support could be established. It is often argued that

companies in the US cannot enter into collaborative research programs may have been true in the past. However, changes have clarified when such collaboration is legal. Companies will need to revisit their decisions on collaborating on research with companies that they compete with in the marketplace.

A recent recommendation of experts was to increase Federal government spending for agricultural biotechnology research to $500 million annually by 1990. Almost all of this would be through competitive grants at the USDA and NSF and would support approximately 3,000 scientists (NRC, 1987). It is questionable whether it is realistic to efficiently attain this level in this short period. However, this appears to be an appropriate level to pursue the research that is necessary to maintain the international leadership that the US has in biotechnology.

While USDA was being criticized for not investing adequately in basic research, other agencies of the Federal government like NSF, NASA, DOE and NIH were funding relevant biotechnology research. In 1984 it is estimated that Federal agencies other than USDA funded $13.6 million or 29% for agriculturally relevant biotechnology research at universities compared to $11.7 million or 25% from the USDA (GAO, 1985). Although this does not detail the specific research or the long term pattern of funding from these

agencies compared to USDA, it does reveal the significant role that other Federal agencies have had in funding agricultural biotechnology research.

Publicly funded agricultural biotechnology research has been pursued to develop basic knowledge which can provide benefits to the public. This is demonstrated by the diversity of Federal agencies funding this research. When companies began looking for opportunities to profit from agricultural biotechnology, it was difficult to link product opportunities to research. It was necessary to build bridges between the present state of knowledge and the product opportunities. The result was the establishment of industrial research groups in basic agricultural biotechnology. The objective of these groups was to overcome the scientific barriers that prevented the accomplishment of product oriented research as quickly as possible. It is widely agreed that the rapidity with which many of these barriers have been scaled is remarkable.

Another approach used to accelerate the development of basic knowledge for agricultural biotechnology has been close relationships with universities. Relationships with universities have been characteristic of the biotechnology industry from its beginning partly because many of the founders of the first companies were university professors. Based on a 1985-86 survey of public and private companies in

the biotechnology industry, agricultural biotechnology companies have one or two university relationships per company. This contrasts strikingly with biotechnology companies in human therapeutics that have seven or more university relationships (Arthur Young High Technology Group, 1986). The reasons for these differences is unclear. However, there may be fewer opportunities for collaboration and the larger companies may substitute relationships with smaller companies for university relationships. Regardless of this relatively low number of university relationships for agricultural biotechnology companies, it is noteworthy to describe some of these relationships because they do contribute to the research performed in the public sector.

Agrigenetics. In a truly pioneering approach, Agrigenetics formed a limited research and development partnership (LRDP) which provided $11 million of research funding to approximately 30 university laboratories over a 5 year period. This LRDP forced many universities to determine if they would accept this industry research money and, if so, under what conditions. It would be interesting to retrospectively analyze this LRDP. Nevertheless, numerous graduate students and post doctoral fellows received support and, most importantly, training with these research funds. Some of the faculty receiving these research grants have distinguished themselves among their peers including election to the National Academy of Sciences. This infusion of

university funding coincided with requests for substantial increases in Federal funding for agricultural biotechnology research which were not being met.

Monsanto. Monsanto was a pioneer among large companies making a substantial, long term commitment to biotechnology research that would allow them to benefit from biotechnology applications to their existing businesses in crop and animal agriculture and to assist them in entering the pharmaceutical business in a new strategic thrust. One component that Monsanto wanted to create was strong univeristy research close to their corporate research in St. Louis, and, therefore, established a 5 year $23.5 million grant with Washington University to accomplish that objective. A grant was established in the Biology Department at the university to support research on Agrobacterium as a vector to transform plant DNA. The results of the vector research contributed to the election of the university researcher to the National Academy of Science and led to what has been recently estimated to be a $45 million per year research effort throughout the plant biotechnology research community (NRC, 1987). This research at Washington University was very relevant to agricultural applications of biotechnology, but was performed at a university that would only receive agricultural research support through the USDA Competitive Grants Program or from other Federal agencies like NSF and NIH.

Post Doctoral Training. Post doctoral fellowships traditionally provide training at universities or public research facilities although there are exceptions in the private sector such as the Roche Institute for Molecular Biology. This industrial post doctoral fellowship concept was followed by ARCO, CIBA-GEIGY and other companies in plant molecular biology. It is too early to analyze the impact of these programs. However, the fellows in these programs were not hired to screen them for full time employment at these companies. These opportunities were presented as a unique exposure to high calibre, multidisciplinary basic research which was difficult to duplicate in university laboratories. The companies that established these programs have benefited from the high calibre of trained researchers they attracted and the latest techniques that they brought with them. It is not clear if companies will continue these programs as competition for resources from product development increases. Regardless, there will be a public benefit from the larger number of scientists trained beyond the PhD during this period than would have been possible if only public funding for this training were available.

Unique Private and Public Funding

The McKnight foundation recently established two 10 year programs for training and interdisciplinary research in plant

biology at universities. The total funding for this was $18.5 million. The Rockefeller foundation has funded programs to link biotechnology to new developments for rice. These efforts are not large but are signigicant in principle.

Different commodity groups have funded applied agricultural research at land-grant universities for many years. However, biotechnology has usually been too fundamental to attract this funding for research.

Several states have established special initiatives in biotechnology and many have programs related to agricultural biotechnology. At least two, Iowa and North Carolina, have special graduate and post graduate fellowships in plant molecular biology. It is too early and the information is too incomplete to assess the impact of these programs on training.

There is an opportunity to expand and redirect some of this unique funding toward agricultural biotechnology research and training.

RESEARCH ON MODEL SYSTEMS

The purpose of both private and publicly funded research until this time was to develop basic knowledge to manipulate agriculturally interesting organisms. The biological systems

that commercial research programs targeted were model systems that were manipulable with modern research techniques and with which their university trained research personnel were experienced. Likewise, the public research community worked with the same model systems because the research would be funded by Federal agencies as the results could contribute to fundamental knowledge of these model systems. Therefore, the systems commonly cited in research by both the public and private sectors include the following model systems:

TABLE 4. MODEL SYSTEMS

Model	Practical End Point
Bacillus thuringiensis	Biological insecticide
Agrobacterium	Disease Resistance in crops
Rhizobium	Nitrogen fixation
Pseudomonas	Plant growth regulator, soil insecticide
Tobacco	Herbicide, disease and insect resistance

During this period of very active basic research by industry, the public knowledge base for agricultural biotechnology has increased dramatically because many of the industrial research laboratories have published extensively and presented their research results at professional meetings.

It is unclear whether this pattern will continue as commercial research becomes more product oriented. Further, companies may not continue the same level of basic research as internal competition increases for development funds.

INDUSTRIAL RESEARCH

EARLY COMMERCIAL RESEARCH

What were some of the product targets companies had on their research agendas? Genentech and the USDA established a collaborative research program to develop vaccines to foot-and-mouth disease of cattle based on the convergence of years of research on coat proteins of this virus by the USDA and the recently established techniques to make proteins from synthesized DNA sequences. Another early target of agricultural biotechnology was a passive vaccine to calf colibacillosis developed by Molecular Genetics. Interestingly, this is considered the first product from modern biotechnology to reach the market. Each of these two examples are for animal agriculture and are concerned with pathogens, one a virus and the other a bacterium. As a consequence, these research efforts benefited substantially from basic research in the mainstream of biotechnology research funded in support of basic knowledge discovery or research supporting human health by NSF and NIH respectively.

Cetus is an example of a company that wanted to find a partner to work with them to build a company based on biotechnology for crop agriculture. Subsequently, they established Agracetus in Madison, Wiscosisn and formed a joint venture with W. R. Grace and Company to develop this company. In 1986, Agracetus performed the first USDA approved field test of plants genetically transformed using r-DNA. From their news release about this test, Agracetus' purpose for this field experiment was to collect information about the yield characteristics of tobacco plants which had been modified to be resistant to crown gall disease caused by Agrobacterium. Although crown gall is not an economically significant disease in commercial tobacco production, this field test was necessary to position Agracetus to apply their technology to other crops and to test the federal and state regulatory apparatus for approving field research of crops transformed with r-DNA. This test also signaled an important transition in the research agenda of industry from fundamental research to development. Until it was possible to transform plants with r-DNA and field test the plants with the objective of improved crop varieties and microorganisms to enhannce crop production, the research agenda of public and private research have been very similar although being pursued for different overall purposes.

PRODUCT OPPORTUNITIES

It is evident the public and private sector converged to develop basic knowledge for agricultural biotechnology research and there will continue to be overlap between the public and private research agendas (Clarke, 1986). Presently, a divergence of effort is occuring as demonstrated primarily by the private companies moving into the developmental phase of research typified by technical and economic demonstration of products such as those listed in Table 5. As an example, the authors estimate that the basic research expenditures range from less than 5% up to 20% of the R & D expenditures of companies in the pesticide industry.

TABLE 5 PRODUCT OPPORTUNITIES

FOR BIOTECHNOLOGY IN CROP PRODUCTION

* Improved Disease Control

* Microbial Manipulation
  - Insecticidal properties of B.t. transfer to Pseudomonas
  - Frost Protection

* Genetically Engineered Seeds
  - Single Genes
    - Herbicide Resistance
    - Improved Nutritional Quality
    - Environmental Resistance
      e.g. Drought stress
      Salt tolerance

  - Multiple Genes (Improved Capabilities)
    * Increased Photosynthesis

  - Multiple Genes (New Capabilities)
    * Biological Nitrogen Fixation

MICROORGANISMS

Microorganisms are absolutely necessary for crop production. For many years farmers have used commercial products containing microorganisms to enhance crop production. There are opportunities to use modern biotechnology to modify microorganisms to further enchance crop production, but these possibilities depend on an increasing base of fundamental knowledge. There are opprotunities which include alternatives to synthetic agrochemicals and fertilizers and as plant protectants. The use of microorganisms as alternative food and feed sources is another target.

Biological Control of Pests

Various microbial toxiphores have potential for the control of insects, weeds and diseases. One example is Bacillus thuringiensis, (B.t.) a bacterium which produces a powerful toxin capable of controlling many lepidopterous insects. Products containing selected isolates of naturally occurring B.t. have been available since the mid-1950's and have benefited from USDA research on B.t. Current B.t. products have two major limitations. First, they control a relatively narrow spectrum of insect species and, second, they require a long time after application to effect economic control. There are substantial efforts both public and private to overcome these two limitations. The authors have identified

at least 12 companies with research programs on B.t. Developent of simple enhancements of activity, for example, a 10% increase in speed of effect would not be a sufficient advance to justify the research investment to develop a new product. This enhancement could not be controlled through protective patents and could not be observed in the field. A major enhancement would be the addition of additional insect species to the control spectrum which would be patentable and could enable the recovery of the research investment by a company.

Another novel approach which requires r-DNA techniques is the splicing of the B.t. gene responsible for the toxiphore into Pseudomonas. It is anticipated that these bacteria when applied directly to seed as a seed treatment or to soil will control the corn rootworm. The corn root worm market is the largest single insecticide market in the US - estimated over $250 million annually. This biotechnology approach is novel and patentably distinct. However, such a product must be efficaceous compared to commerical standards as well as competitive biological products and must negotiate an uncertain regulatory environment because of its novelty. This uncertain regulatory environment and market opportunity increase the risk of any industrial research project.

Plant Growth Regulators

Microorganisms have plant growth regular potential illustrated with the ice-minus example of Pseudomonas syringae. In this instance, the gene responsible for the protein which initiates ice crystal formation in plants and subsequent frost damage to crops is in Pseudomonas that naturally reside on plants. When the gene which codes for this protein is deleted by genetic engineering. It is theorized that these modified bacteria would protect crops from frost if they replaced the natural population on plants. The original research on this phenomenon was at the University of California at Berkeley although this is now a commerical target. The field experiments to test the practical utility of the ice-minus bacteria was initiated this spring after four years of litigation and regulatory delay.

Crop Nutrition

Another potential application of agricultural biotechnology is enhanced biological nitrogen fixation by improved Rhizobium. Techniques used include selection and r-DNA. If successful products are developed, they would ultimately reduce the amount nitrogen fertilizer produced and applied to crops.

One point to make here is the potential conflict of interest between nitrogen fixing bacteria and conventional nitrogen

fertilizers. Would a corporation which manufactures and sells nitrogen fertilizer consider developing a Rhizobium that might ultimately reduce the need for manufactured fertilizer? Companies should not allow their fertilizer interest to negate their biotechnology program because some company will achieve the goal of reduced fertilizer usage. Business wisdom would indicate that it is wise to replace your own product, i.e., nitrogen fertilizer with your own improved product, Rhizobium. Unfortunately, this wisdom may not prevail. One needs only to look as far as the American automobile industry which did not recognize the market opportunity for smaller cars to realize how slowly an industry can respond to changes in the marketplace.

Food Resources

The use of microorganisms as a source of protein was one of the initial applications of biotechnology. ICI developed the world's largest fermenter to grow a bacterium, Methylophylus sp., which produced single cell protein from methanol for use as a feed supplement for animals. Because of today's low price for soybean meal, this fermenter is idle and the limited specialty sales of the protein supplement, Pruteen, are supplied from inventory (Sherwood, 1984; Jacobson et. al., 1986).

ICI's experience definitely dented their plans for

biotechnology. However, from the Pruteen experience, ICI was able to recognize the significance of using a mycoprotein as a food source. This resulted in the formation of Marlow Foods, a joint venture between ICI and Ranks Hovis McDougall to produce and sell Quorn, a mycoprotein enriched food. It also served as a "cash fly wheel" while unique prospects for biotechnology in agriculture are developed (Financial Times, 1987).

Process Technology and Engineering

Major consideration has been given to the use of single cell proteins, various monomeric chemicals and complex polymers. However, it is extremely difficult to obtain precise financial and operating information on industrial processes. This is because processes generally reflect relatively minor improvements or are considered obvious and not patentable. Regardless, this technology is critical to making a product and is, therefore, proprietary information. Consequently, much of the needed expertise remains within the organization which initially developed it. Once established, however, process technology can become a major strenth for a company, and technology not readily transmitted to another group.

Economic Incentives

Industrial research and development are driven by the

economic incentive to make a profit. For example, in Table 6 potential sales estimates for agricultural biotechnology derived products from an SRI study are presented (Graulier, 1986).

TABLE 6 PROJECTED MARKETS FOR AGRICULTURAL BIOTECHNOLOGY PRODUCTS

Target	Estimated US Sales ($ x million)		
	1990	2000	2025
Disease Resistant Plants	12	178	325
Pesticide Resistant Plants	2	200	430
Biological Pesticides	24	154	220
Biological Metabolites	3	27	50
Disease Detection	8	22	34

Source: SRI, 1984 from M. Graulier, Research in Biotechnology, Special Issue III, Champs du Monde, Rhone - Poulenc Agrochemie, 1986.

Industrial funding of agricultural biotechnology research is and will increasingly be directed toward areas which are likely to yield a high return on investment to the company, usually, in the shortest possible time.

One of the great strengths of the private sector is the ability to move an invention from discovery to commercialization. Successful development depends on a continuous process of goal setting and measurement of progress

against time and costs. The initial enthusiasm for the prospects of manipulating plants, animals and microorganisms with biotechnology for agriculture is in the middle of translation into products, and the reality of time, costs and profit are in front of all agricultural biotechnology research groups in companies large and small.

The market for a product is critical to the success of research. There are no absolute rules to determine the size of a market needed to support the development of an agricultural biotechnology product, and the economic attractiveness of a product will vary from company to company. However, it is certain that a company intends to recover all of its costs to develop that product on a discounted basis plus a premium for the risks it has taken. Further, these profits must pay for unsuccessful developments and new product research and development which has not reached the marketplace. Based on the pesticide industry it would not be unusual to expect a return on investment of 45 to 75% on an annual basis for a proprietary product.

Based on the $150 million estimated for industrial agricultural biotechnology research in Table 2 and investing 10% of sales in R & D, there should be $1.5 billion in agricultural biotechnology product sales. This projected sales level is between one and two magnitudes too high. Compare this to the pesticide industry, the biggest R & D

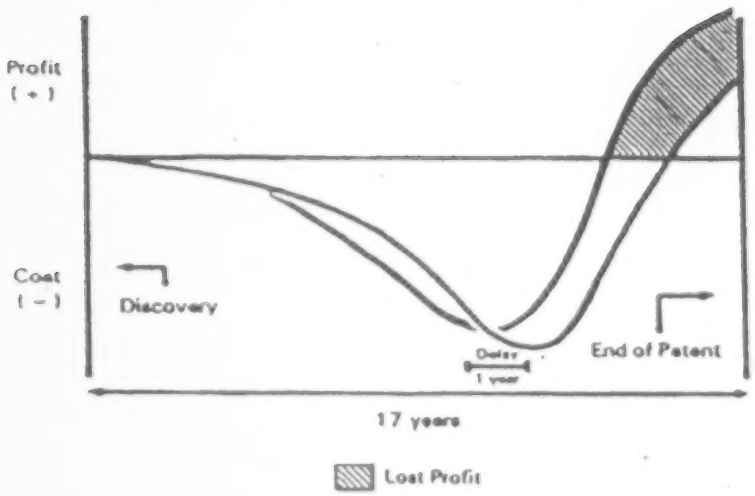
performer of all agricultural industries, where 5-8% of sales are invested in R & D and total US pesticide sales are $8-9 billion (ARI, 1985). Further, it is important to observe the consolidation of the pesticide industry where 10 years ago approximately 40 companies were performing research to discover new products. Today, there are approximately 18 companies doing discovery research. This consolidation of research is demonstrated by acquisitions during the last 18 months in which Dupont acquired Shell, Rhone-Poulenc acquired Union Carbide, and ICI acquired Stauffer. The consequence of this is that fewer companies are able to afford the R & D necessary to compete in this industry. Consider the total industrial expenditure for R & D in agricultural biotechnology or that 42% of the expenses for agricultural biotechnology companies are for R & D (Arthur Young High Technology Group, 1986), one must conclude that there is a major emphasis to develop products to financially justify the research investment in agricultural biotechnology. It is uncertain what balance industrial agricultural biotechnology research will establish between basic research and product development, but it is certain that more resources must go toward product development.

There is a bias in a financial analysis that favors a highly profitable market and a large market. As for the agricultural biotechnology research agenda in the private sector, a company can wait longer and take greater risks for a large market.

This perspective results in a focus on opportunities for major crops like soybeans, corn, wheat, cotton, etc. which follows the traditional pattern for chemical pesticides. Specialty crops like peas and kiwi fruit represent niches which may not benefit equally from agricultural biotechnology research by the private sector unless the market opportunity is highly profitable or the useful technology from another system can be used directly.

Unanticipated technical or regulatory delays can have a dramatic effect on the profitability of products and the commercial agricultural biotechnology research agenda. In Figure 1, a one year delay has resulted in a 50% reduction in profit during the product life cycle and can have a detrimental impact on cash flow. Using Dupont's recently introduced herbcide, Glean, as an example from the pesticide industry, first year sales were $40 million (Wall Street Journal, March 30, 1984). If there had been a one year delay in product approval by EPA, Dupont would have had to manage the impact of this unrealized cash flow. In crop agriculture, there is an amplified sensitivity to delays because a one month delay at a critical time can result in missing one entire year of development. Certainly the delays in conducting field trials of agricultural biotechnology products reduces anticipated profits and the 4 year delay experienced with the ice-minus Pseudomonas field testing represents a major risk that will be factored into the R & D process for

FIGURE I: Impact of Delay on Profit



SOURCE: Harrett, 1986.

all agricultural biotechnology companies. Additionally, the cost of initial field trials and the associated regulatory approvals is presently very high and becomes an additional burden that agricultural biotechnology products must pay for. The outcome of this factoring is that long term research investments may be jeopardized.

Patents

Patents are a critical dimension in managing risk in commercial biotechnology research. Although the patent situation for biotechnology discoveries will continue to evolve in the US and other countries, companies assume that their discoveries will be patentable and, if they require enabling patented technology, there is an opportunity to license that from its owner. The exclusive business that can develop from a patented discovery provides a longer period to recover costs associated with product research and development. It is too early to determine whether the existing patent life is useful or whether the technology will change so quickly like in microelectronics that a product will be displaced by a superior product before the applicable patent expires. It seems reasonable to assume that the extensive applications research necessary to develop a biological product will result in reasonable product life cycles although this is not guaranteed. For plant biotechnology products in the US, there is potentially patent

coverage under a Plant Variety Patent at the USDA or under a patent from the Patent and Trademark Office. This idiosyncracy adds to the complexity of managing intellectural property for plant biotechnology. However, equally or more important to this characteristic of US patents is harmony with foreign patents because of the global economy in which agriculture operates. For example, how do US plant variety patents compare and contrast with European plant variety protection and should steps be accelerated to coordinate the critical requirements of each? At the other extreme from the discovery is the regulatory approval process. As mentioned earlier, the length of time required to accomplish regulatory approval and the uncertainty associated with field testing add to the risk a company takes and can reduce the effective patent life for a product. For pharmaceuticals, there is patent extension possible based on the period of time the product is under regulatory review. Likewise, there should be patent extension for agricultural biotechnology patents to compensate for the uncertain regulatory environment. This protection would influence companies to undertake higher risk agricultural biotechnology research and contribute to the competitiveness of this industry.

Biological Characteristics

The intrinsic characteristics of biological materials must be factored into the commercial research and development of

biotechnology products for agriculture. Biological materials tend to be highly specific as described earlier regarding B.t.. This contrasts with a broad spectrum synthetic pesticide. This specificity may result in other favorable characteristics like susceptibility to degradation, minimal effect on non-pest organisms, management of resistance to chemical pesticides and public acceptability. It could be this very specificity that limits the market opportunity for these biotechnology products, and does not provide the economic incentive for companies to develop products. This dilemma should be factored into setting publicly funded research priorities. There is a precedent for this public involvement in product development to provide a benefit to the farmer. This precendent is the Federally funded IR 4 program which is used to establish pesticide tolerances for minor use crops. There may be a need to provide public resources to obtain regulatory approval of selected biotechnology products for agriculture.

The research agenda of companies is not easy to document and assess for agricultural biotechnology. However, research is often initiated based on that company's strengths in research, production or marketing (OTA, 1984). Table 7 indicates the relative strengths of several companies in agricultural biotechnology and their existing business activities. Although this does not necessarily indicate their current research effort, it does suggest a likely direction for

research because successful companies usually build on positions of strength.

TABLE 7

RELATIVE STRENGTHS OF SELECTED MAJOR AGRICULTURAL BIOTECHNOLOGY ORGANIZATIONS

Company	Associated Seed Company	Strengths[a]		
		Research and Development	Production[b]	Marketing to the Farmer
ABBOTT	o	+	++	+
CALGENE	DeKalb +	+	o	+
CIBA-GEIGY	Funk +	+++	+	+++
AMERICAN CYANAMID/ ECOGEN/MOLECULAR GENETICS	Pioneer +++	++	++	+++
DUPONT/SHELL	o	+++	+	++
GRACE/AGRACETUS	o	++	o	++
GENETICS INSTITUTE	United Agriseeds	+	o	+

ICI/STAUFFER	Garst +	+++	+++	+++
LILLY/HYBRITECH	o	++	+	++
MONSANTO	Harts	+++	+	+++
MYCOGEN	o	+	o	o
PPG/SCRIPPS	o	+	o	+
RHONE-POULENC	o	+++	o	++
SANDOZ	Northrup King +	++	+	++
SHELL INTERNATIONAL	o	++	o	++
UPJOHN	Asgrow +	+	++	+

a.

o = Unaware of existing capability

+ = Low Activity

++ = Moderate Activity

+++ = High Activity

b. Fermentation capability and expertise

Changing Market for Agricultural Products

The global market for agricultural products has changed during the 1980's. Early in the decade public policy and the agricultural research agendas of the public and private sectors were driven by the objective of increasing agricultural production. This emphasis was supported by doomsday projections of population growth exceeding the world's ability to feed itself. These projections are found in many reports that influenced public policy on agricultural research, for example, The Global 2000 Report (CEQ, 1980) and Agricultural Research until 2030 (Johnson and Wittwer, 1984). These projections were incorrect, and, in spite of continuing population growth, the agricultural productivity of the developing countries of the world has resulted in real increases in average per capita protein production worldwide. This is illustrated in Table 8 where protein production has increased 8.4% annually from 1981 to 1985 (Hudson, 1985). There is greater resiliance in the world's agricultural productivity than ever experienced.

How does this change in agriculture products and markets influence agricultural biotechnology research? The objective of US agriculture has changed from producing to feed the world to emphasizing the profitability of farming. Accordingly, the objective of agricultural research in the United States is to increase net farm income (USDA, 1985; Marshall, 1986). During this dramatic change, agricultural biotechnology research in the

public and private sectors was being launched to benefit the public and the agricultural industry. This change in agriculture presents a difficult challenge to closely examine research objectives of both the public and private sectors to determine if the outcome of successful research will improve profitability for the farmer.

Kalter (1985) has examined the impact of bovine somatotropin in dairy farming in the United States and concluded that this product will definitely effect the profitability of milk production being positive under some conditions and negative under other conditions. This kind of analysis will be increasingly required when research is initiated and when products of biotechnology approach the marketplace (OTA, 1984). It is reasonable to expect that the farmer will need an analysis for his particular set of conditions when he is deciding whether to buy or use a biotechnology product. Where the farmer will obtain these analyses remains to be determined. However, the Agricultural Extension Service, private consultants and banks will all be involved.

TABLE 8 FOREIGN PROTEIN PRODUCTION

YEAR	WORLD POPULATION (10 6) EXCLUDING USA	FOREIGN PROTEIN PRODUCTION (MMT) TG=10% OL=40%	FOREIGN PROTEIN PRODUCTION PER CAPITA
81/82	4275	159	82.2
82/83	4352	165	83.7
83/84	4429	174	86.4
84/85	4506	183	89.7
	5.4% INCREASE PER ANNUM		8.4% INCREASE PER ANNUM

SOURCE: W. J. Johnson, Factors Affecting Competition of US Agriculture, Agricultural Research Institute, Proceedings 34th Annual Meeting, 1985, 61.

SUMMARY

US agriculture has undergone changes over the last decade from producing high yields on each acre to producing a quality product at minimum cost. These changes have resulted partly from the adoption of new agricultural technology in other parts of the world and general food surpluses. The significant impact for US agriculture is reduced commodity prices and reduced export markets. This situation painfully demonstrates the sensitivity of US agriculture to exports and international trade. To regain lost export markets and to prevent further erosion of these markets, it is imperative that the agricultural research agenda is re-examined to insure that it reflects food surpluses. The Economic Research Service of the USDA has indicated that the best long term solution to increase agricultural exports is by lowering production costs (GAO, 1987). Biotechnology is a major technology input for the future and there is an opportunity to reevaluate agricultural biotechnology research for financial yield to the farmer rather than high biological yield.

The paper has attempted to examine the funding of agricultural biotechnology research and assess the importance of funding source on research agenda. This analysis of public and private funding of agricultural biotechnology research reveals several important findings.

There is an important, ongoing question about how funding influences the selection of research agenda. The answer to this question is always changing and should always be asked when changes are considered in the public research agenda for agricultural biotechnology. Some overlap between the public and private research agendas should be expected for effective, beneficial innovations to occur.

Agricultural biotechnology research should be target for substantial funding increases. Biotechnology is a small proportion of the total R & D funding in the agricultural public and private sectors - between 5 and 10%. This level appears to be considerably less than the amount necessary to enable biotechnology to evolve to a new stage in agriculture. To meet the changed objective - from biological to financial yield - requires an integrated approach to agricultural production and, particularly, for, agricultural biotechnology research.

Although basic research in agricultural biotechnology by the private sector has uniquely contributed to fundamental knowledge, basic research by the industrial sector may not play a major role in the future. It appears that only the public sector can be depended on to generate fundamental knowledge for agricultural biotechnology. Since the present funding of public research by the private sector is

relatively small, it is very doubtful that there is a major opportunity for support from industry for major public research initiatives. Yet, the results of that basic research must be available to industry for their expensive development of products. Industry must grasp its responsibility to support excellence in agricultural biotechnology research. Assuming it is desirable for industry to contribute to fundamental knowledge, it is necessary to establish a reasonable opportunity for industry to recover it's investment, e.g., exclusive licenses, patent extensions, collaborative research.

Traditional agricultural research will be effected by biotechnology and by the changes in agriculture. For example, traditional university departments like agronomy, plant pathology, and soils should balance research programs with agricultural needs and new technology like biotechnology rather than continue research programs because that is where their faculty has expertise and has published.

The success of the agricultural research enterprise has depend on effective technology transfer through publicly supported extension. The future extension of applications of agricultural biotechnology to the farmer will require understanding biotechnology and the implications of biotechnology on the profitability of the individual farm product. The mechanisms of technology transfer are changing

and the training of personnel, especially those in the Agricultural Extension Service, will change. The Agricultural Extension Service must provide options to the farmer with clear implications for each option like the cost per unit and the impact on the quality of the product.

One of the major benefits to emerge from the increased industrial biotechnology research in agriculture has been the formation of new alliances and relationships between industry and non-agricultural universities and the basic sciences. These relationships should be encouraged and strengthened as resources and sources of new ideas.

Superficially, for industry the selection of its agricultural biotechnology research agenda is relatively simple. It must be anticipated that the research investment will generate a reasonable return on investment. This requires the definition of a product, process or service, its economic value, and the length of time required to develop the product or service. Winners and losers will be sorted out in the long run by their ability to generate new and profitable products. This analysis suggests that research funding in the industrial sector for agricultural biotechnology is considerably higher than the most research intensive segments of industrial research and specifically agricultural research but comparable to biotechnology in general. To justify this continued level of industry funding will require substantial

product sales with high profitability.

The public research agenda in agricultural biotechnology has been selected in a variety of methods, for example, peer review, national and international workshops, legislative mandate. Current mechanisms may be adequate to determine the priorities in public research; however, there may be opportunities to expand on the national network proposed by the Division of Agriculture of the National Association of State Universities and Land Grant colleges for the coordination of resources in biotechnology research through the National Biological Impact Assessment Program. As stated previously, the overlap of research between the public and private sector contributes to effective innovation. Innovation is enhanced by incentives to the private sector like exclusive licenses to patentable discoveries developed in the public sector. Conversely, there are potentially biotechnology products which can contribute to strong agriculture but are too risky for industry to perform the necessary R & D. Mechanisms and institutions should be considered to identify, perform and manage targeted R & D for important but risky needs in agriculture.

American agriculture is one component in a global agricultural scene. Global agriculture has changed rapidly during the last decade and is now facing the major dilemma of food and feed surpluses and a depressed agricultural economy.

The dilemma is a fabric of interwoven problems for which there are no simple solutions and which may be very delicate.

Biotechnology certainly cannot be expected to resolve the dilemmas of US agriculture. However, with careful and appropriate guidance, biotechnology has the potential to provide new technology options which could contribute significantly to successful agriculture. For this single reason, the public and private sectors have a vested interest in insuring a successful flow of new knowledge and profitable products and processes to agriculture. This outcome requires that adequate resources are invested in a public and private agricultural biotechnology research agenda that reflects the complexities of agriculture requiring increased net farm income.

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